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FIRE CONTROL RADAR SPECIAL CIRCUITS

INFORMATION, EXPERIMENTS AND APPLICATIONS

TRAINEE'S GUIDE
for
FIRE CONTROL TECHNICIAN TRAINING

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WASHINGTON 25, D. C.

FIRE CONTROL RADAR SPECIAL CIRCUITS
TRAINEE'S GUIDE, NAVPERS 92213

1. This publication has been prepared for use as a text at the Fire Control Technician School, Class "A", and at other locations where such subject matter is required. The Instructor's Guide, NavPers 92212 is the complementing text for the course.

2. Corrections and recommendations for changes to this publication are invited. Commanding Officer, Service School Command, San Diego, California, has been assigned clearing house responsibility for evaluating and compiling recommended improvements, and for submitting them to the Chief of Naval Personnel in the form of a proposed change. Users of this course material are requested to submit their recommendations directly to the command having clearing house responsibility with a copy to the Chief of Naval Personnel (Attn: Pers-C1123).

P. S. Smith

P. S. SMITH
Captain, USN
Director, Instructional Standards
and Materials Division

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NAVPERS 92213

FIRE CONTROL RADAR SPECIAL CIRCUITS

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HOW TO USE THIS TRAINEE'S GUIDE

TECHNICAL TRAINING

This Trainee's Guide has been prepared to place emphasis on the practical training of the technician in the operation and maintenance of radar fire control equipment. All Navy technicians are expected to be craftsmen - not engineers or designers - and they will learn their skill by doing.

PUBLICATION

This publication, now in your custody, is your guide for use during this portion of the course. Since it will be forwarded to you after you have completed the course, it is suggested that you use its pages for any useful notes.

STUDY ASSIGNMENTS

Study assignments in this publication will be made by your instructor. Some time will be available for study during the regular school day, but additional study will be necessary. Assignments, covering the material to be discussed the following day, will normally be made at the end of the preceding school day.

SAFETY NOTICE

WARNING

The attention of all hands is directed to Section V, Chapter 67 of Bureau of Ships Technical Manual or superseding instructions on the subject of safety.

Extreme caution must be observed when working with fire control systems and associated equipments. Dangerous voltages are present at all times, and contact with them can result in permanent injury and death. While every practical safety feature has been incorporated in this equipment, the following rules must be observed strictly.

KEEP AWAY FROM LIVE CIRCUITS:

Operating personnel must at all times observe all safety regulations. Do not change tubes or make adjustments inside equipment with high-voltage supply on. Under certain conditions dangerous potentials may exist in circuits with power controls in the off position due to charges retained by capacitors. To avoid casualties always remove power, and discharge and ground circuits prior to touching them.

DO NOT SERVICE OR ADJUST ALONE:

Under no circumstances should any person reach within or enter the enclosure of (for the purpose of servicing or adjusting) the equipment without immediate presence or assistance of another person capable of rendering aid.

DO NOT TAMPER WITH INTERLOCKS:

Do not depend upon door switches or interlocks for protection but always shut down motor generators or other equipment. Under no circumstances should any access gate, door, or safety interlock switch be removed, short-circuited, or tampered with in any way (other than for replacement) without the specific authority of the Bureau of Ships. Personnel must not rely upon the interlock switches to remove dangerous voltages from the equipment. Periodic tests and inspections must be made on these devices to ensure that they are operating correctly.

RULES REGARDING CIRCUITS EMPLOYING 300 VOLTS OR MORE:

Voltages in excess of 300 volts shall not be measured by probing or holding the test probe in the hands. Whenever measurements are necessary on equipment employing potentials in excess of 300 volts or where rubber gloves cannot be worn, the following precautions and procedures shall be observed:

The equipment shall first be de-energized.

High-voltage capacitors shall be discharged with a suitably insulated shorting- or grounding-bar.

The technician shall ascertain that test equipment controls are set correctly for testing high voltage.

Test leads capable of carrying high voltage shall be secured on the desired test point by the technician.

The technician shall withdraw the equipment under test, making sure that he is also free from leads and in a good position for making correct meter readings.

The equipment shall be energized by an assistant standing by the switch.

After the necessary reading is made, the equipment shall be de-energized and high voltage capacitors shall be discharged.

The foregoing steps shall be repeated as necessary for each measurement.

GENERAL NOTES (WHICH CAN SAVE YOUR LIFE):

Make certain that you are not grounded whenever you are adjusting equipment or using measuring equipment.

In general, use only one hand when servicing live equipment.

If test meter must be held or adjusted while voltage is applied, ground the case of the meter before starting measurement, and do not touch the live equipment while you are holding the meter. Some moving vane type meters should not be grounded; thus they should not be held during measurements.

Do not forget that high voltages may be present across terminals that are nominally low voltage due to equipment malfunction or breakdown. Be careful even when measuring low voltages.

Do not use test equipment known to be in poor condition.

High-voltage, high-capacity capicitors should be discharged with an insulated shorting- or grounding-bar with approximately 10 ohms in series with the grounded line.

Where neither terminal of a capacitor is grounded, short the capacitor terminals together.

Take time to be safe.

RESUSCITATION

An approved poster illustrating the rules for resuscitation by the Holger-Nielsen method shall be displayed prominently in each radio, radar, or sonar enclosure. Posters may be obtained by request to the Bureau of Medicine and Surgery.

Another effective means of administering artificial respiration is the mouth-to-mouth resuscitation method. Familiarization with this method is important particularly if the victim has above the waist injuries—broken bones, burns, etc. —or if the space is too confining for the Holger-Neilson method. The following procedure and cautions will serve as a guide for using the mouth-to-mouth resuscitation method.

1. Clear the mouth of foreign objects with the middle finger of one hand. With the same finger, press the tongue forward.
2. Place victim in a face-down, head-down position, and pat firmly on the back with free hand. This should dislodge any foreign objects in the air passage.
3. Place victim on back, and use middle fingers to literally lift lower jaw so that it "juts out." This is accomplished by placing fingers beneath jaw bone and behind it on a line almost perpendicular to ear. Using one hand, hold jaw in this position.
4. Use thumb and first finger to close nostrils by reaching over forehead to grasp nose of victim, making leakproof seal.
5. Place your mouth over the victim's mouth, making a relatively leak-proof seal.
6. Breathe into victim's mouth with a smooth steady action until you observe chest rise.
7. When lungs are inflated, remove your lips from victim's mouth and allow lungs to empty. Repeat this cycle every 5 seconds.
8. If at any time resistance to breathing is detected and victim's chest does not rise, place victim in face-down head-down position and pat firmly on back, then quickly resume mouth-to-mouth resuscitation.

Points To Remember

Aspects of concern when placing victim in resuscitation position or in interim between cycles:

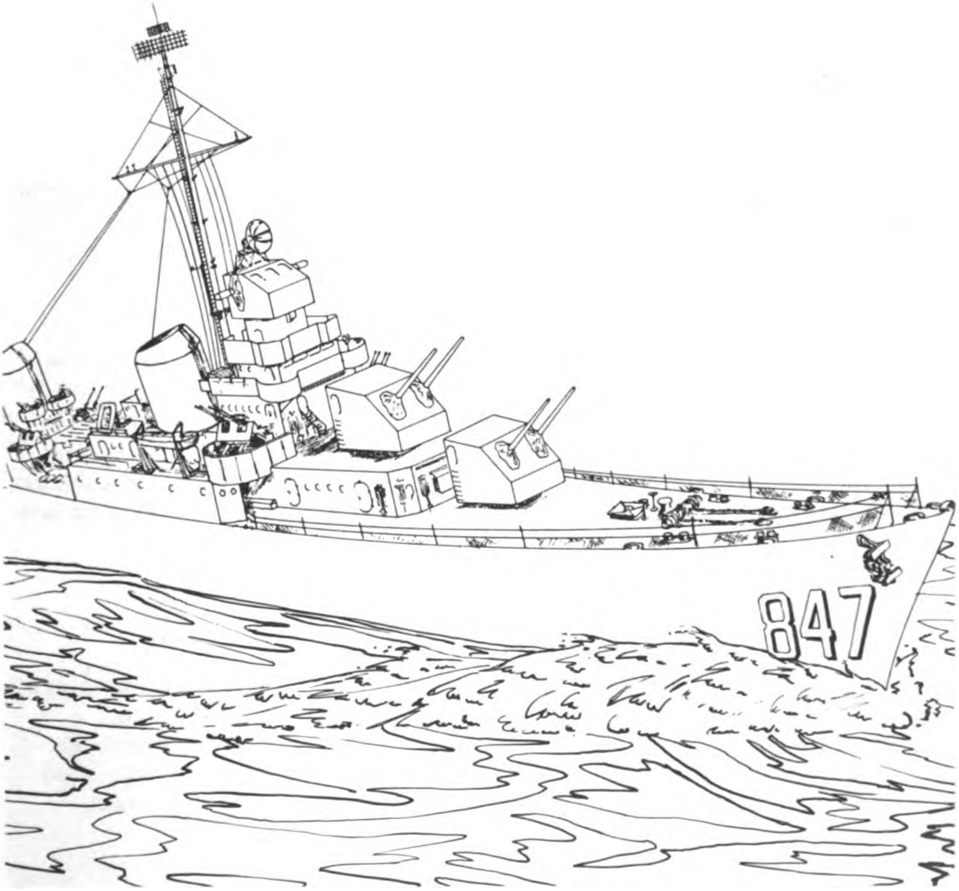
1. Body should be inclined slightly in such a way that fluid drains better from respiratory passage.
2. The head should be extended (not flexed) forwarded and chin should not sage. Obstruction of respiratory passage may occur if this is not done.
3. Check that tongue or foreign matter is not obstructing air passage.
4. A smooth rhythmetic cycle is important; split-second timing is not essential.
5. Once respiration has been restored, keep victim warm and absolutely quiet. Do not permit victim to sit or stand up.

TOPIC 1: INTRODUCTION TO FIRE CONTROL RADAR SPECIAL CIRCUITS

Your Progress up to Now

Your goal is to gain all of the knowledge and practical skills necessary to enable you to operate, maintain, and adjust modern Navy fire control radar systems. Up to now, you have advanced a great part of the distance toward that goal. Your courses in "Basic Electricity" and in "Basic Electronics" gave you a foundation in basic principles that you will use in the courses that follow.

You have begun your study of radar fundamentals by finding out about radar—what it is, what it can do, and why it is important to the Navy. You found out that a radar system consists basically of a transmitter, a directional transmitting and receiving antenna, a receiver, and an oscilloscope. You have seen how radar works by sending out strong pulses of high-frequency radio waves and by receiving the echoes reflected from objects in the path of these waves. You have examined illustrated examples of how ships, planes, and bodies of land are detected, and you have learned of some of the factors that limit radar operation. You have learned some of the features of fire control radar equipments.



1. --The need for fire control radar special circuits.

INTRODUCTION TO FIRE CONTROL RADAR SPECIAL CIRCUITS

Why You Must Learn about Radar Special Circuits

At this stage of your training, you must realize that you cannot work efficiently with radar equipment without having mastered the special circuits involved. To try to do so would be very much the same as going ahead without a knowledge of power supplies, amplifiers, or receiver circuits. It would mean that as soon as you got started on any part of a radar system, you would run into a special circuit, and you would have to take time out to learn about it. In this way, your mastery of the radar would be constantly interrupted by a seemingly never-ending flow of new circuits.

When you get into the details of the study of radar equipment, you will be most interested in how the various circuits are arranged to make up a complete system. Your job will be to learn the operation of the system, and how to maintain and trouble shoot it. If you can approach this assignment with a well-rounded knowledge of special circuits and some practical experience in working with them, your job will be just that much easier.

Since it is to your best interest to gain a knowledge of special circuits before you go on to work with radar systems, that is just what you are going to do now.

Special Circuits You Will Learn about

There are only three basic groups of special circuits—generating circuits, shaping circuits, and connecting circuits.

Generating Circuit

A generating circuit originates a signal that is required for the proper operation of the radar equipment but, since the signal does not exist elsewhere, it must be "generated;" that is, "created" by a generating circuit.

Shaping Circuit

A shaping circuit works with signals that are fed into the equipment from the outside, or with signals that are generated within the equipment itself. When these signals do not have the shape that is required for the proper operation of the equipment, a shaping circuit is used. This type of circuit may be used to change a sine wave into a square wave, or a square wave into a sharp voltage pulse. Shaping circuits may cut the tops or bottoms off existing waves.

Connecting Circuit

The purpose of a connecting circuit is to take the output of one circuit and connect it to another. A connecting circuit may be used as an impedance-matching device between two stages in order to prevent the second stage from loading down the first. Connecting circuits may also be used as switches to connect one circuit to another only at certain desired times.

INTRODUCTION TO FIRE CONTROL RADAR SPECIAL CIRCUITS

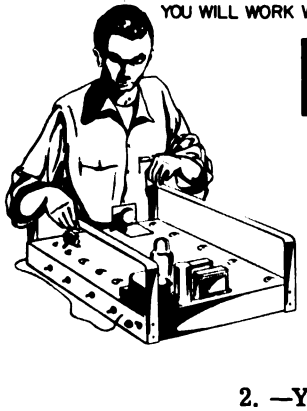
How You Are Going to Learn about Fire Control Radar Special Circuits

Fire control radar equipments are composed of circuits that you have already learned and a large number of special circuits. A special circuit found in one radar equipment may be identical to the same type of special circuit found in another equipment, or it may contain a number of variations. A thorough understanding of radar special circuits will mean that your learning of any radar equipment will be made much easier.

The special circuits included in this course are found in Navy fire control radar equipments. Any special circuit that is in common use has been included. Special circuits that are found in only one fire control radar equipment have not been included, as they will be taught with the specific equipment involved. Instead of simply reading about the circuits, you are going to work with many of them. Then you will see examples of these circuits as they are found in specific fire control radars.

The special circuits included in this course are divided into two groups. The first group includes special circuits that are used very frequently and which are simple enough to be built on a chassis, so that you can get some practical experience in working with them. As far as these circuits are concerned, you will learn about them in just the same way as you learned about the circuits in your course in "Basic Electronics." You will read information sheets concerning each circuit and its common variations, and then discuss the principles of operation with your instructor. Once this foundation is well established, the instructor will demonstrate the operation of the circuit built on the chassis. He will show you this circuit operating under normal and abnormal conditions, and he will show you how to test, adjust, and trouble shoot it. After that you will use a model of the same chassis, and you will have the opportunity to work with each circuit yourself. In this manner, you will gain some first-hand experience in observing, testing, adjusting, and trouble shooting most of the special circuits that are commonly used.

You will read information sheets concerning the second group of special circuits and will discuss each one in detail with your instructor. You will not see these circuits demonstrated nor have the opportunity to work with them on a chassis. These circuits were not included in the chassis because they required high voltages for their operation, or required too many components, or some of the components are too bulky.



YOU WILL WORK WITH

INFORMATION, DEMONSTRATION AND EXPERIMENT SHEETS FOR CIRCUITS THAT ARE SIMPLE ENOUGH TO BUILD ON A CHASSIS

AND, IN ADDITION WITH

INFORMATION SHEETS ONLY ON CIRCUITS THAT ARE IMPRACTICAL TO BUILD ON THE CHASSIS.

2. —You will build a chassis.

INTRODUCTION TO FIRE CONTROL RADAR SPECIAL CIRCUITS

How You Are Going to Learn about Fire Control Radar Special Circuits (Continued)

The presentation of materials on each special circuit included in the chassis will follow this general sequence.

General Purpose of the Circuit in Radar.

How It Works.

Some of Its Variations.

The Chassis Circuit.

Experiments.

Trouble shooting.

Applications of the Circuit to Fire Control Radar Equipments.

Review.

The applications of the special circuit will be found in examples taken directly from the Ordnance Pamphlets for the following fire control radar equipments:

Radar Equipment Mark 25 Mod 3

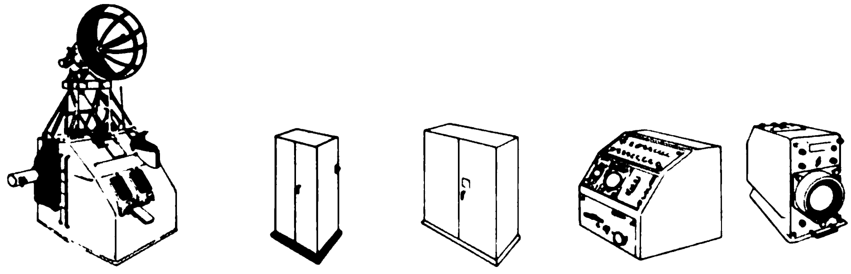
Radar Equipment Mark 35

Radar Equipment Mark 34

Radar Set AN/SPG-34

Radar Set AN/SPG-48

Radar Set AN/SPG-50



3. —Just a few you'll see.

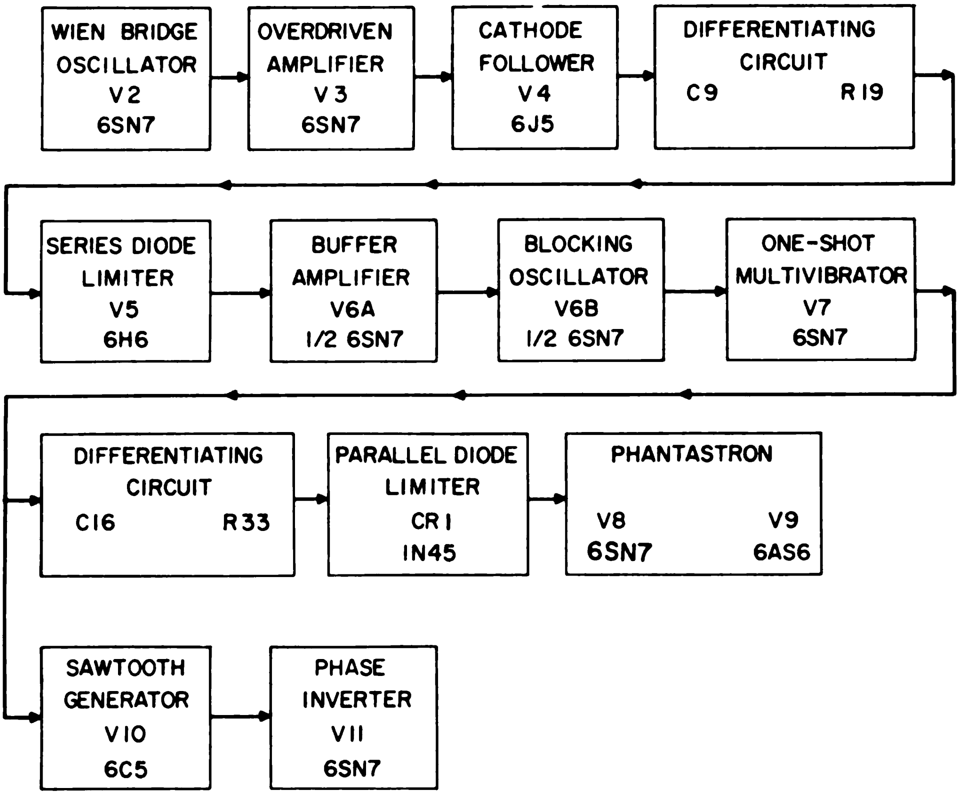
INTRODUCTION TO FIRE CONTROL RADAR SPECIAL CIRCUITS

The Special Circuits Chassis

A special circuits chassis has been designed for your use in this course. By means of this chassis, you will be able to get practical working experience with eleven special circuits and with a number of variations.

The chassis will be wired completely when you get it, and the only wiring that you will be required to do will be to make minor changes in the circuit to alter it into some of its common variations. At this stage of your training, you should have had sufficient experience with wiring, and it is more important for you to use the time available working with circuits rather than building them.

The block diagram below shows the special circuits that are included in the chassis and the sequence in which they are connected. You will work with these circuits in the same order as they are shown—beginning with the first stage, the Wien bridge oscillator, and ending with the last stage, the phase-inverter.

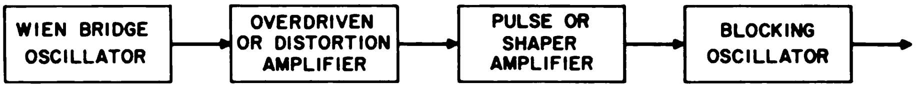

WIEN BRIDGE OSCILLATOR V2 6SN7
OVERDRIVEN AMPLIFIER V3 6SN7
CATHODE FOLLOWER V4 6J5
DIFFERENTIATING CIRCUIT C9 R19
SERIES DIODE LIMITER V5 6H6
BUFFER AMPLIFIER V6A 1/2 6SN7
BLOCKING OSCILLATOR V6B 1/2 6SN7
ONE-SHOT MULTIVIBRATOR V7 6SN7
DIFFERENTIATING CIRCUIT C16 R33
PARALLEL DIODE LIMITER CR1 1N45
PHANTASTRON V8 6SN7 V9 6AS6
SAWTOOTH GENERATOR V10 6C5
PHASE INVERTER V11 6SN7

4. —Special circuits chassis—block diagram.

The Sequence of Special Circuits on the Chassis

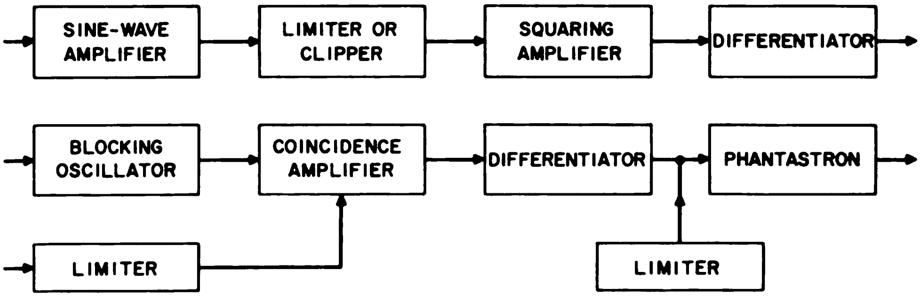
There are two general reasons for the particular arrangement of the special circuits on the chassis. First, the circuits are in the order in which they might be arranged in a typical radar. Second, special signal generators are not required since the type of signal needed to test and trouble shoot a circuit will be found at the output of the preceding stage. The only test instruments generally called for in the various demonstrations are a 'scope and a multimeter.

Let us examine some of the arrangements of these special circuits as they are found in fire control radar equipments. In the radars that use a Wien bridge oscillator to establish the repetition rate of the radar, you will find this sequence—Wien bridge oscillator, overdriven amplifier, pulse or shaper amplifier, and blocking oscillator.



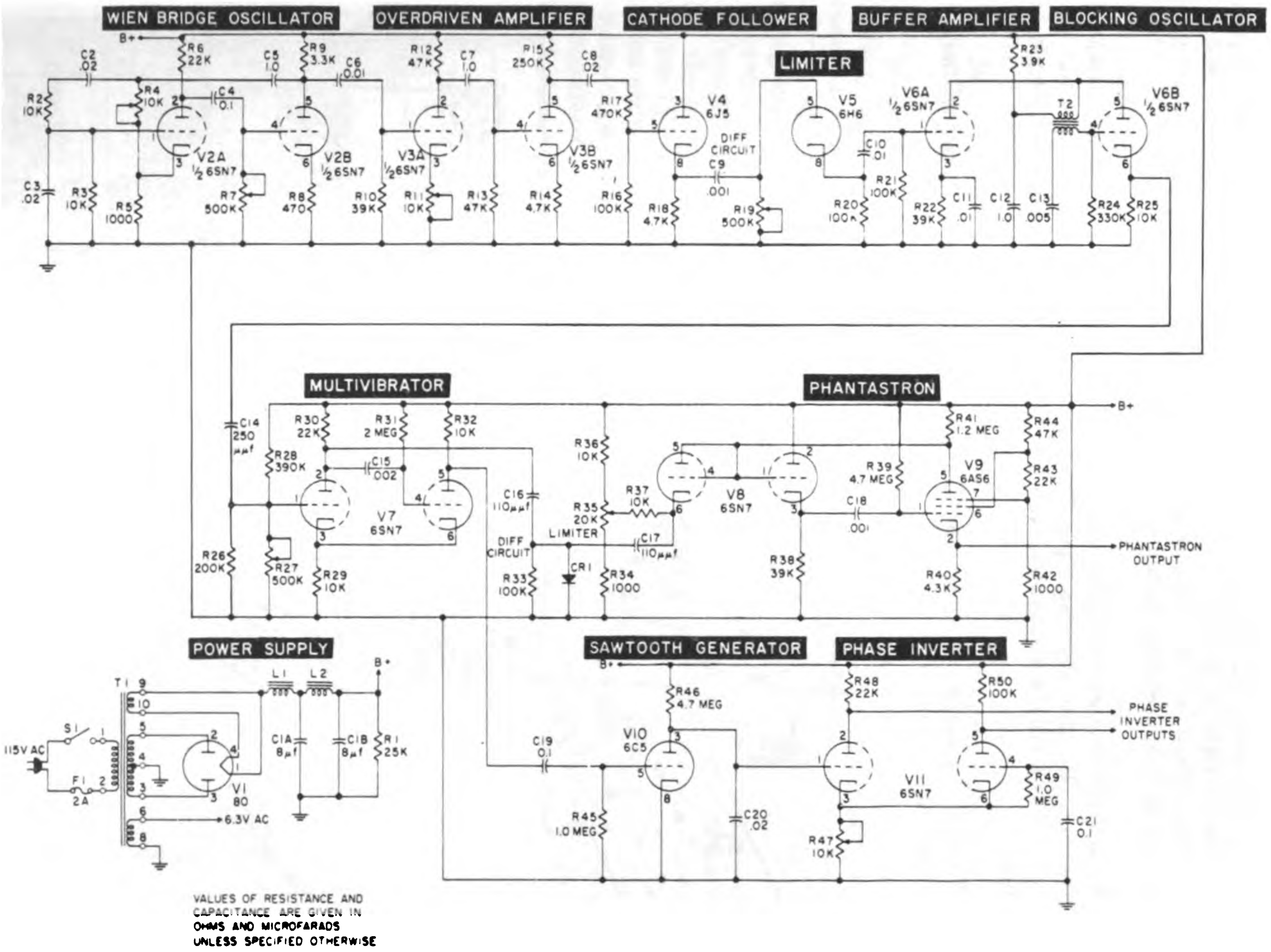
5. —Repetition rate sequence block diagram.

Two more sequences of special circuits from fire control radars are shown in block diagram form. Compare these sequences actually used with the sequence found in the special circuits chassis. You will note that a portion of a radar equipment is composed of combinations of radar special circuits. The sequence of these special circuits may be very similar to the arrangement in the chassis, or there may be wide variations.



6. —Multiple sequences block diagram.

The other reason for the sequence of the circuits in the special circuits chassis is to facilitate testing and trouble shooting. The sequence is so arranged that the required signal for testing a circuit is generally available as the output of the previous stage. This eliminates the necessity for special signal generators, such as square wave, pulse, and sawtooth-type generators, that otherwise would be required for the demonstrations, experiments, and trouble shooting.



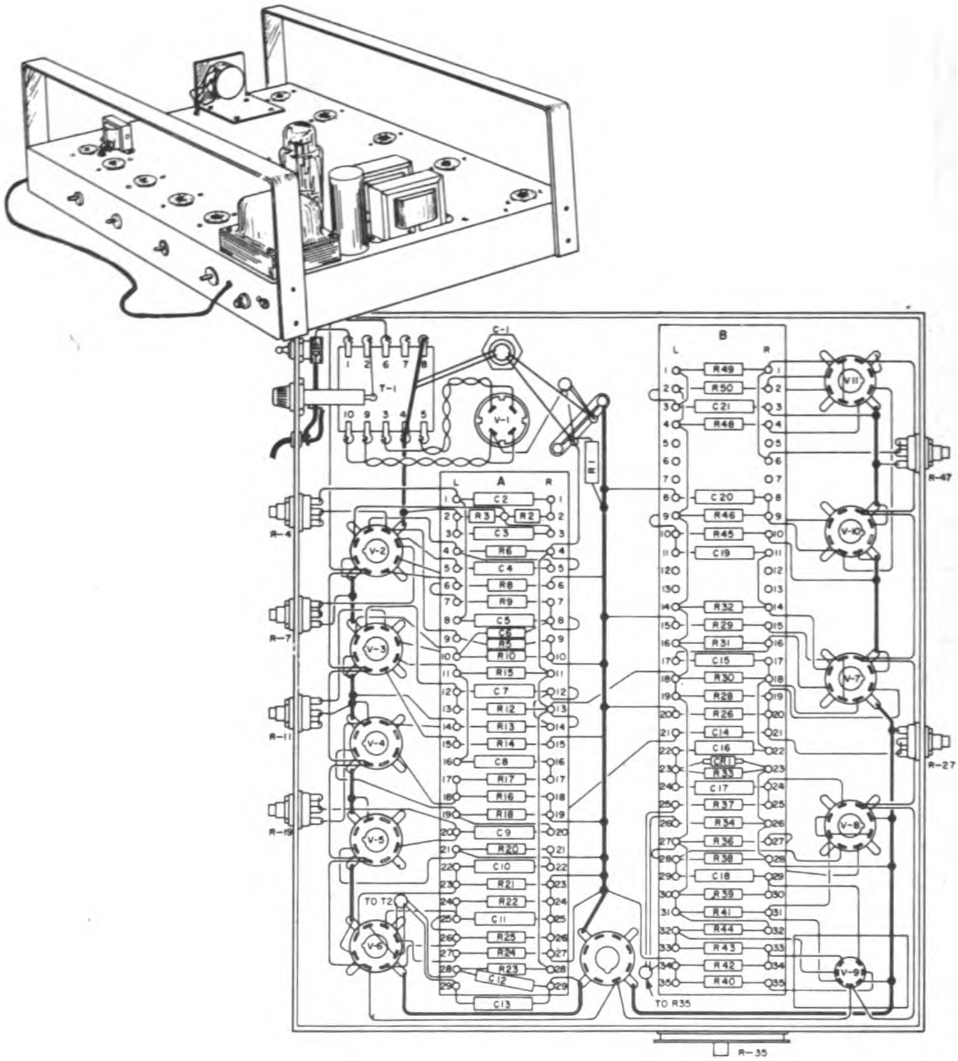
7. —Schematic diagram.

Schematic and Wiring Diagrams (Continued)

When checking, adjusting, or trouble shooting fire control radar equipments, the technician always has a schematic and a wiring diagram of his equipment. These are his two essential tools. You will also require these tools, and they are shown on these pages.

In many fire control radar equipments, test points are provided on the chassis. In your chassis, specific test points are not provided, but adequate check points are available at the terminal strips and at the tube sockets.

Component layout enables you to modify the circuits to some of their more common variations.



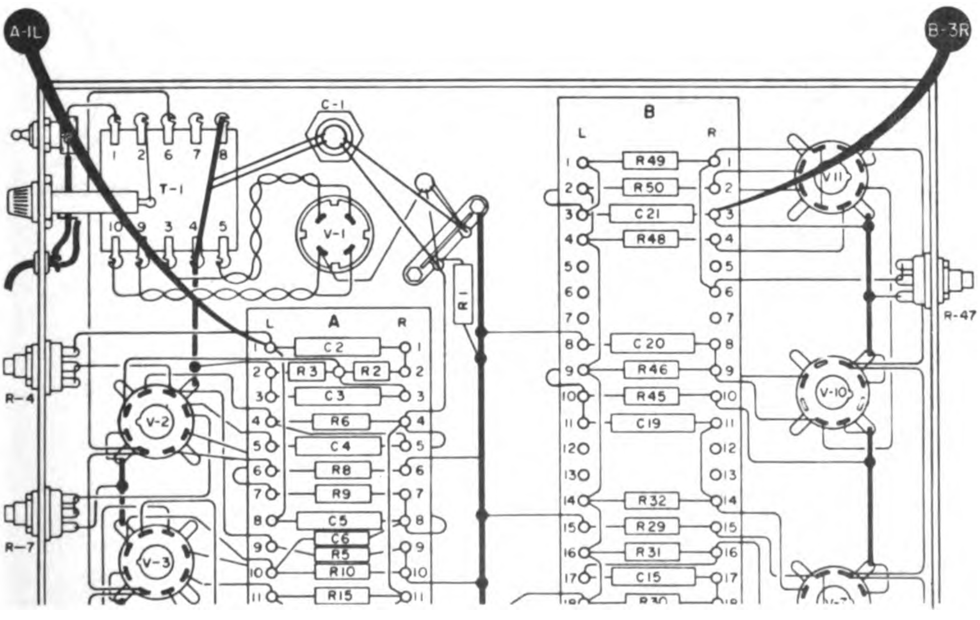
8. —This is your Special Circuits chassis.

INTRODUCTION TO FIRE CONTROL RADAR SPECIAL CIRCUITS

The Special Circuits Chassis—Location of Check Points

Since nearly every check point in all of the circuits that are included in the chassis is connected to a point on one of the terminal boards, there is a quick way of indicating the terminal to be used as a check point. Rather than using a verbal description of where the terminal is located, it is assigned its own code symbol on the chassis. Symbols such as A-1L and B-3R are used. The symbols tell you the exact location of the terminal in question. These symbols will be used in the experiments in the early part of the course. However, it is expected that as you become more familiar with the chassis these symbol designations will no longer be required, and they have not been included in the experiments toward the end of the course.

Refer to the illustration below and you see that there are two boards—one lettered "A" and the other "B." Notice that there are two rows of terminals on each board, and that each terminal receives a number as shown. In addition, terminals on the left side of each board are assigned the letter "L" and those on the right are assigned the letter "R." Therefore, the code symbol "A-1L" means that the terminal in question is on board A and is the first from the top on the left side. Similarly, symbol "B-3R" means that the terminal is on board B and is the third from the top on the right side. In the experiments on the chassis, the various check points will be referred to by these symbols, and you will be able to locate them immediately. In your experiments, all voltmeter and 'scope connections marked with a terminal number indicate that the test instrument is connected across that point and the chassis ground.



9. — Special circuits chassis terminal coding system.

Other Special Circuits

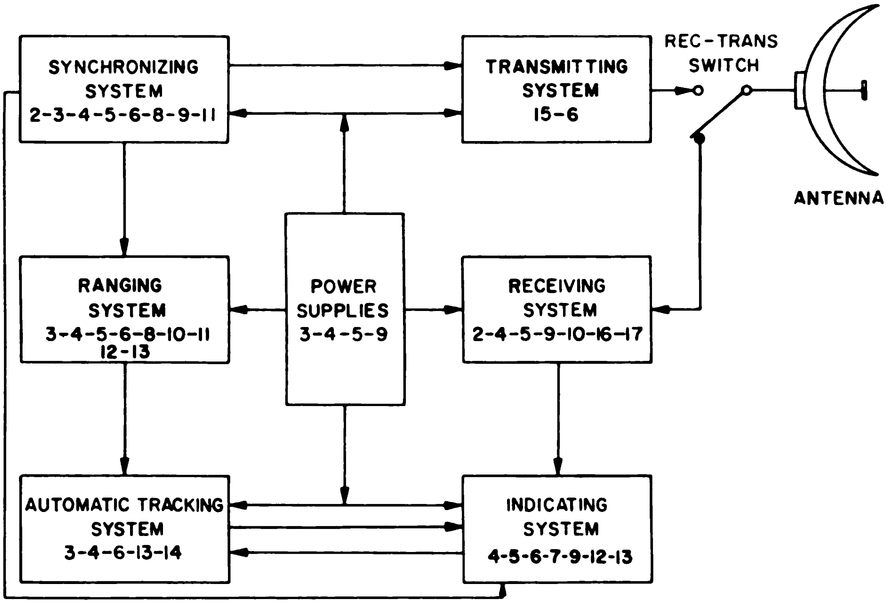
In addition, special circuits that are not in your chassis will also be discussed. These circuits will generally be covered from the standpoint of their operation, purpose, effects on system operation, trouble analysis, and corrective action required. Also, a specific application of each of these circuits as they appear in a fire control radar will be illustrated.

These circuits are as follows:

1. Coincidence Amplifiers
2. Error Detector Circuits
3. Magnetron Oscillator
4. Radar Converters and Klystrons
5. Discriminators in AFC Circuits
6. The Duplexer (Rec-Trans Switch)

LOCATION OF SPECIAL CIRCUITS IN A TYPICAL
FIRE CONTROL RADAR EQUIPMENT

TOPIC	TOPIC TITLE
2.	AUDIO OSCILLATORS
3.	LIMITING CIRCUITS - AMPLIFIER TYPE
4.	CATHODE FOLLOWERS
5.	DIFFERENTIATING CIRCUITS
6.	LIMITING CIRCUITS - DIODE TYPE
7.	CLAMPING CIRCUITS (DC RESTORERS)
8.	BLOCKING OSCILLATORS
9.	MULTIVIBRATORS
10.	THE PHANTASTRON
11.	COINCIDENCE AMPLIFIERS
12.	SAWTOOTH GENERATORS
13.	PHASE-SHIFTING CIRCUITS
14.	ERROR DETECTOR CIRCUITS
15	THE MAGNETRON OSCILLATOR
16	RADAR CONVERTERS AND KLYSTRONS
17.	DISCRIMINATORS IN AFC CIRCUITS


SYNCHRONIZING SYSTEM 2-3-4-5-6-8-9-11
TRANSMITTING SYSTEM 15-6
REC-TRANS SWITCH
ANTENNA
RANGING SYSTEM 3-4-5-6-8-10-11 12-13
POWER SUPPLIES 3-4-5-9
RECEIVING SYSTEM 2-4-5-9-10-16-17
AUTOMATIC TRACKING SYSTEM 3-4-6-13-14
INDICATING SYSTEM 4-5-6-7-9-12-13

10. —Typical fire control radar equipment.

Notes

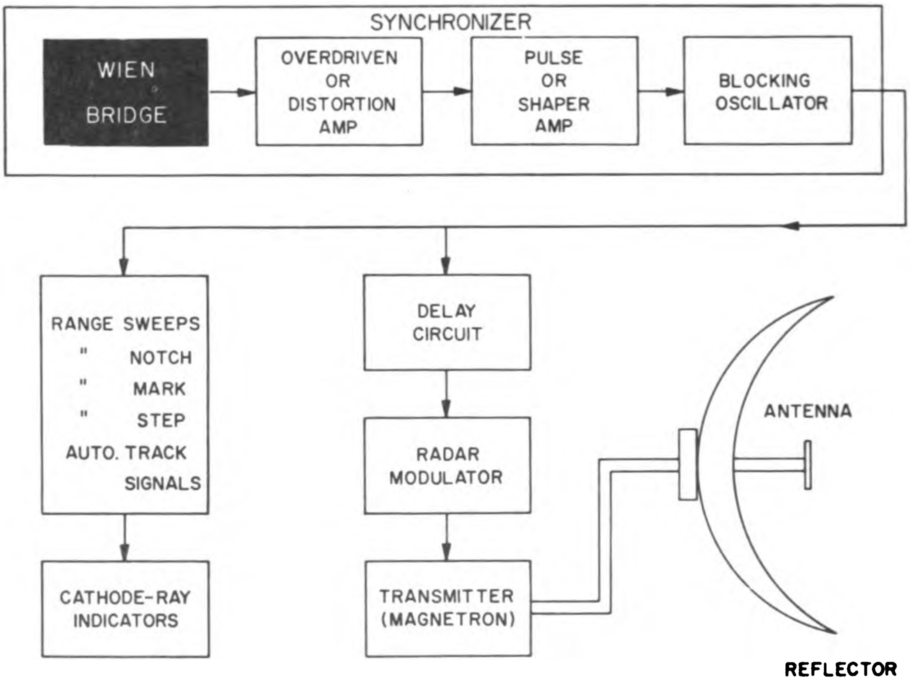
TOPIC 2: AUDIO OSCILLATORS

General Purpose in Radar

Fire control radar systems use several types of audio oscillators to develop electrical pulses for a number of uses. Some types are used to develop a sine-wave voltage with a high degree of frequency stability. One of these types is the Wien bridge oscillator. This oscillator is used in the Synchronizer (Synchronizing System) of several fire control radars. Its function is to develop the pulse repetition frequency (PRF) of the radar. This oscillator controls the timing pulses occurring in the various units of the radar. It will operate during the entire time that the radar is energized.

Pulses occurring at the frequency of the Wien bridge oscillator are used to trigger the radar modulator. The radar modulator develops the high-voltage pulses at this same frequency. These high-voltage pulses enable the transmitter to develop the high-powered burst of RF energy.

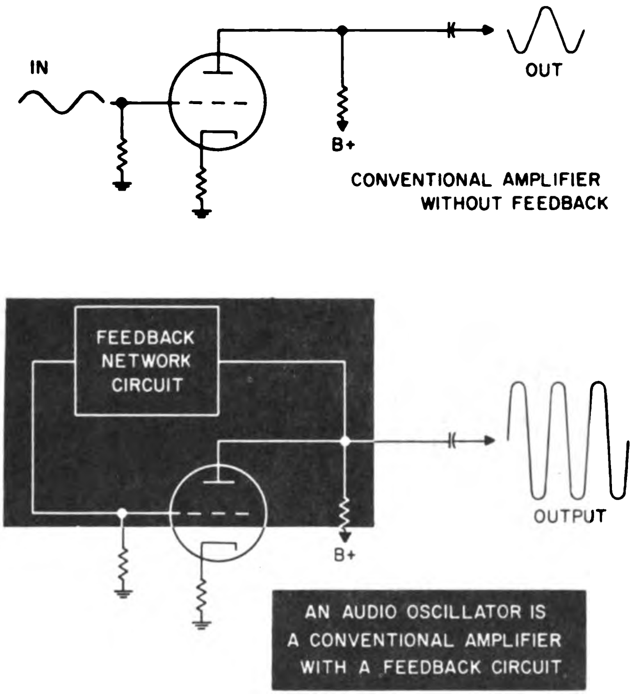
Pulses at the frequency of the Wien bridge oscillator are also used to initiate the sweeps and the range measuring signals. These signals have a definite time relationship with the transmitter pulse. These time relationships are controlled by the Wien bridge oscillator.



11. —Function of the Wien bridge oscillator.

General Purpose in Radar (Continued)

You know from your work with radio frequency oscillators, when you first studied oscillators in "Basic Electronics", that any amplifier will oscillate if some of its output of correct phase and amplitude is fed back to the input. That is what an audio oscillator is - a conventional audio amplifier with a feedback circuit which feeds some of the output signal back, in proper phase and amplitude, to the control grid. The feedback circuit is made frequency selective, so that only signals of the desired frequency are fed back with sufficient amplitude to cause oscillations. The result is an audio oscillator which generates a sine wave of the desired frequency.

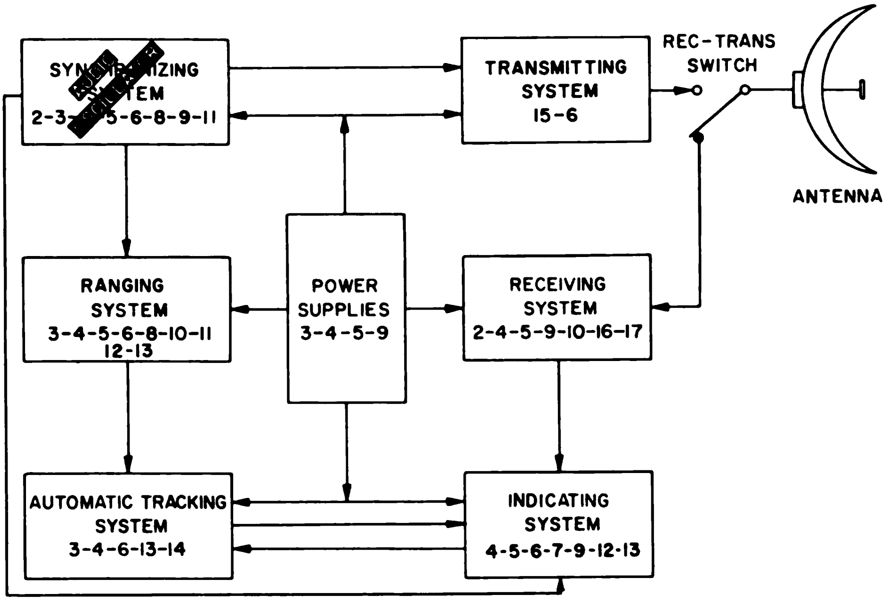


12. — Audio oscillator.

You now have a circuit which generates a sine-wave signal that can be used to produce the desired pulse repetition frequency for a radar set.

General Purpose in Radar (Continued)

The audio oscillator, which determines the repetition rate at which the magnetron is turned on, must be very stable. This means that if a pulse repetition rate of 2000 pulses per second is desired for a particular radar system, the audio oscillator must put out a sine wave of 2000 cycles per second with as little change of frequency as possible. The repetition rate of a particular radar is determined by the maximum range desired. Commonly used pulse repetition frequencies are in the range from 1000 cycles to 3000 cycles per second.



13. — The audio oscillator in action.

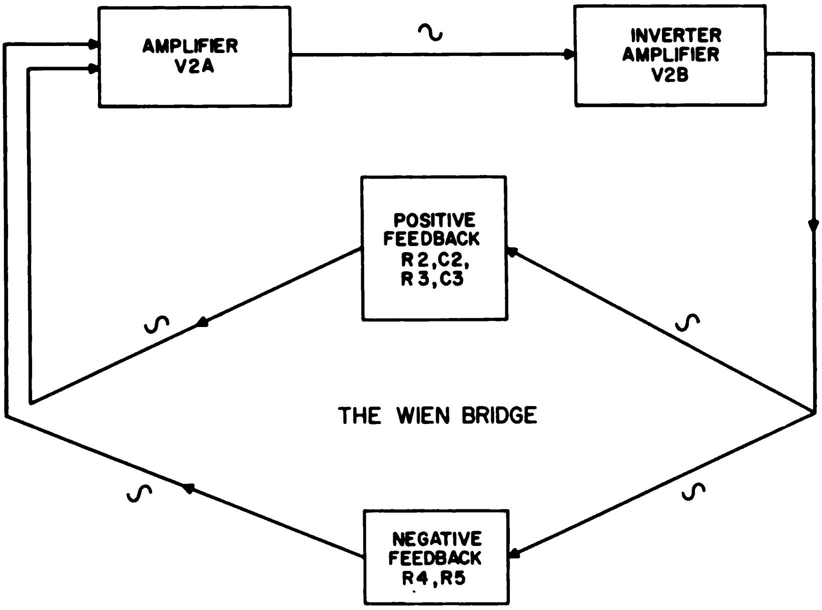
You know that a vacuum tube, by virtue of being an amplifier—having greater signal output than signal input, can be made to act as a generator simply by feeding back only a part of the output in proper phase relationship to the input, or grid circuit. Any small electrical disturbance in the circuit is thus amplified, fed back to the grid, and further amplified and fed back to the grid—resulting in oscillation.

An audio oscillator which generates a signal with good frequency stability is the Wien bridge oscillator, and this is the form of audio oscillator that you will test and trouble shoot.

The Wien Bridge Oscillator

The Wien bridge oscillator is so named because it provides feedback by means of a circuit similar to that developed by the physicist Wien for use in frequency measurements.

In using a vacuum tube as a generator, it is essential that suitable precautions be taken to stabilize the oscillator with respect to frequency, amplitude, and composition of the waveform. In RF (as contrasted to audio) oscillators, these factors are realized by employing a properly designed circuit of inductance and capacity. In the Wien bridge oscillator, frequency selective arms of a bridge circuit are used to provide the regenerative feedback from the output circuit to the input circuit, so that oscillations can be initiated and maintained. The purely resistive arm of the bridge (R4 and R5) provides a degenerative or controlling voltage to the cathode of V2A for the purpose of stabilizing overall operation. Note that the same phase of voltage is used for both positive (regenerative) feedback and negative (degenerative) feedback.



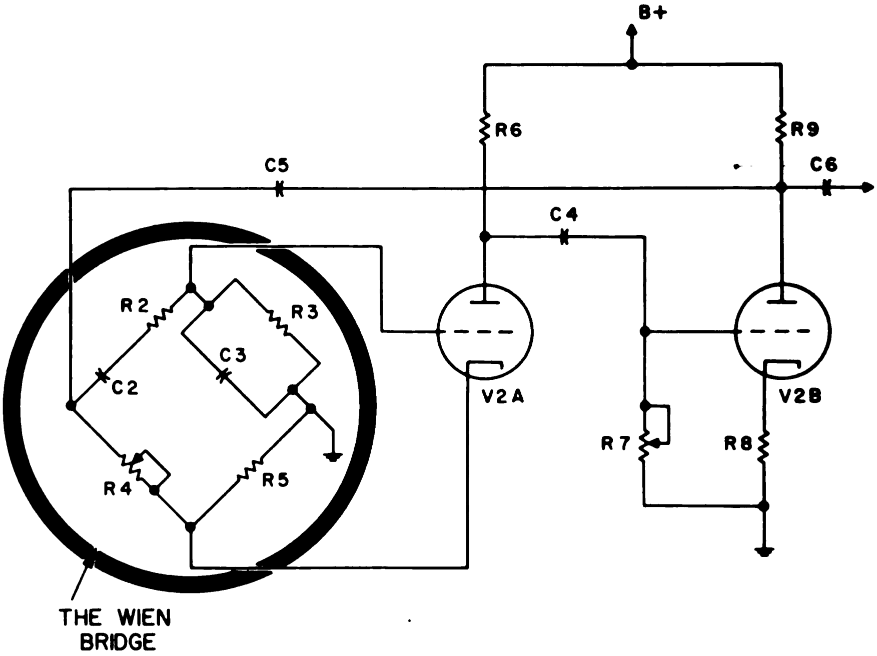
14. — The Wien bridge.

The Wien bridge oscillator consists of an amplifier tube (V2A) and a feedback circuit.* The feedback circuit is composed of amplifier-phase-inverter tube (V2B) and the Wien bridge. The phase inverter inverts the phase of the signal coming from the amplifier plate, so that it will be the correct phase to reinforce the signal on the amplifier grid. The bridge circuit is used to eliminate the effectiveness of feedback voltages of all frequencies, except the single frequency desired in the output.

The Wien Bridge Oscillator (Continued)

After the signal is amplified and inverted in phase by V2B, it is fed to the frequency-selective Wien bridge.

If a frequency-selective bridge of resistors and capacitors was not included in the feedback circuit, the resulting oscillation would be unstable and there would be no easy way to adjust the circuit to the desired signal frequency. The Wien bridge arrangement allows only a signal of the desired frequency to arrive back at the control grid of the amplifier tube with enough amplitude to cause oscillations to build up. Since V2B is an amplifier as well as a phase inverter, it gives enough voltage gain to overcome any losses at the desired frequency caused by the Wien bridge.

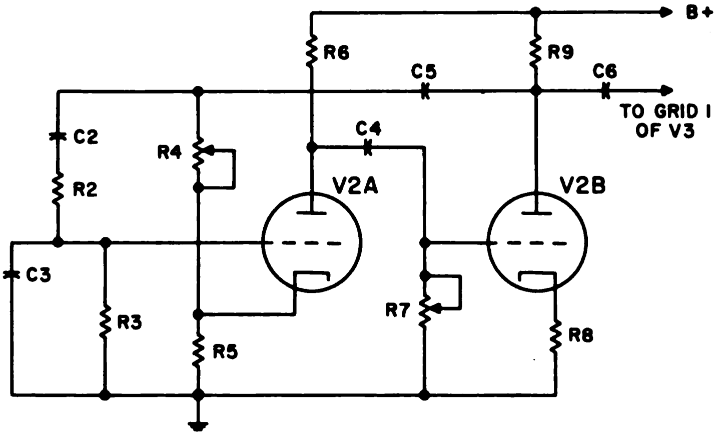


15. — The Wien bridge oscillator.

In order to bring out its frequency-selective characteristics, it is necessary to connect the Wien bridge so that there is positive feedback to the grid and negative feedback to the cathode of the amplifier tube. When the bridge is correctly balanced, the positive feedback will just exceed the negative feedback and the circuit will then generate an undistorted sine wave at the selected frequency.

Seeing How a Wien Bridge Oscillator Works

In the experiment included later in this topic, you will work with a Wien bridge oscillator. By means of an oscilloscope, you will observe its operation by viewing the voltage waveforms at various points in the circuit. You will measure the output frequency by comparing it with the output of a signal generator, and you will change the value of certain circuit components and note the effect on the output frequency.

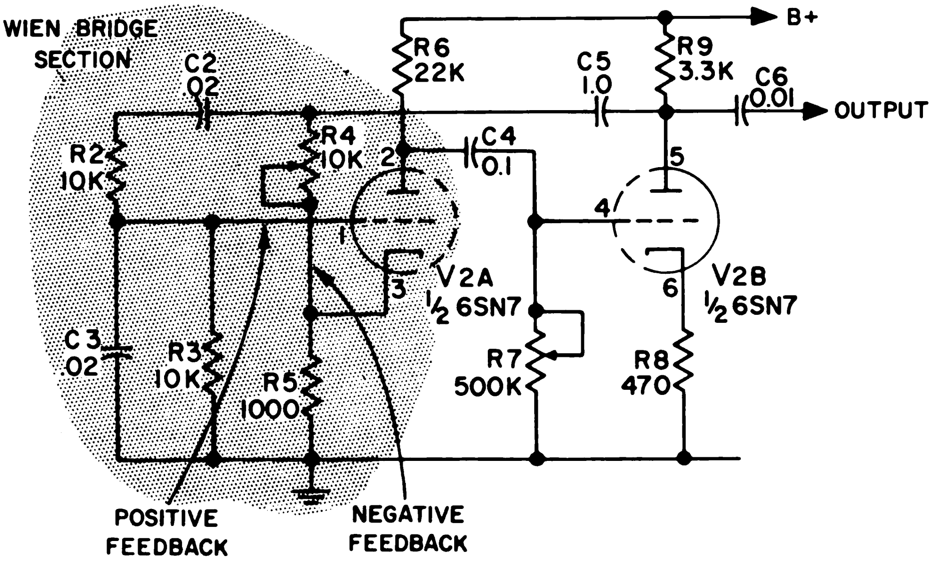


16. —Wien Bridge oscillator circuit (I).

Consider now how oscillations start in the Wien bridge oscillator circuit. As power is first applied, there will be surges of plate current through each of the two tube sections. The voltage developed across R6 will be coupled through C4 to the grid of V2B. The initial surge of current through R9 will develop a voltage that is coupled through C5 to the grid circuit of V2A. This action produces various frequencies in the output of V2B, but only one frequency will reach the grid of V2A with the correct phase and amplitude to reinforce circuit action and produce oscillations. This one frequency will be amplified and inverted in V2A, amplified and inverted in V2B, and arrive back at the grid of V2A in phase with the signal that produced it. Various frequencies are present in the circuit, but oscillations will occur at only this one frequency.

Seeing How a Wien Bridge Oscillator Works (Continued)

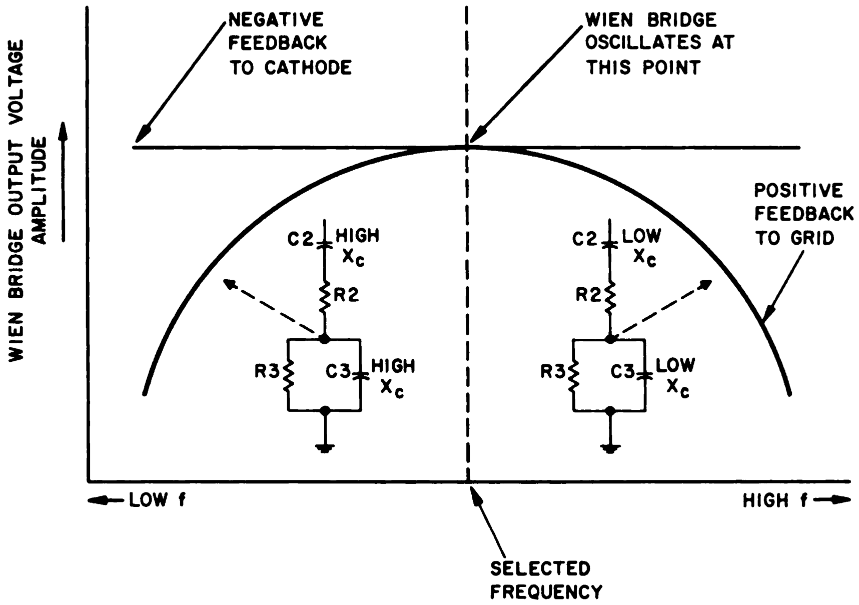
A portion of the voltage output of V2B is fed back through the 1-mfd capacitor, C5, to the Wien bridge network (R2, R3, R4, R5, C2, and C3), and then to the grid and cathode circuits of V2A. The voltage fed to the grid is provided by the voltage divider formed by R2, C2, R3, and C3. This is the positive, or regenerative, feedback. The voltage fed to the cathode is provided by voltage divider R4 and R5. This is the negative, or degenerative, feedback. Positive feedback adds to the input of V2A and increases the output, while negative feedback subtracts from the input and decreases the output. In order that oscillation take place, the positive, or regenerative, feedback to the grid must exceed the negative, or degenerative, feedback to the cathode.



17. —Wien Bridge oscillator circuit (II).

Since there is no phase shift across the voltage divider, R4 and R5, the negative feedback is constant for all frequencies; since R4 is variable, the amplitude of the negative feedback can be controlled.

Seeing How a Wien Bridge Oscillator Works (Continued)



18. —Output voltages of the Wien bridge.

As shown above, the positive feedback is at its maximum at a certain frequency, which depends upon the value of the components in the positive feedback voltage divider. These are R2, R3, C2, and C3. The values of these components are chosen so that the network will produce maximum voltage at the grid of V2A at only one specific frequency.

Since the negative feedback is constant, the circuit will be degenerative at all frequencies where the positive feedback is less than the negative feedback. The circuit is designed so that the positive feedback becomes **greater than the negative feedback only at the desired frequency, as shown in the graph. If the frequency is reduced toward zero, the current that can flow through either C3 or R3 is reduced to almost zero by the high reactance of C2, and the voltage between the grid of V2A and ground becomes almost zero. On the other hand, if the frequency is very high, the reactance of the capacitors is almost zero. In this case, R3 is shunted by the very low reactance of C3, making the voltage between the grid of V2A and ground almost zero. At some frequency between these limits, the positive feedback voltage is at a maximum, as shown in the graph. Oscillations can take place only at the frequency at which the voltage across R3, the input voltage to the grid of V2A, is in phase with the output voltage of V2B and the positive feedback voltage exceeds the negative feedback voltage.**

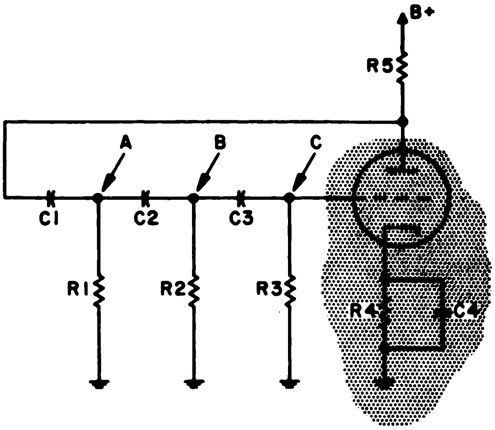
The Phase-Shift Oscillator

The Wien bridge oscillator is not the only type of audio oscillator used in radar equipment. The phase-shift, sine-wave oscillator is also used in some radars. In order for this oscillator to work, the signal fed back to the grid must be 180 degrees out of phase with the signal on the plate. The Wien bridge oscillator uses a second vacuum tube to accomplish this phase shift in its feedback circuit. The phase-shift oscillator does not use the second tube, but uses instead a phase-shifting circuit composed of capacitors and resistors. These components shift the phase of the plate signal 180 degrees before applying it to the grid of the oscillator. The phase-shifting circuit is frequency selective, so that only the desired frequency is shifted 180 degrees. Any other frequency appearing in the circuit does not arrive at the grid in the proper phase to sustain oscillations.

A phase-shift oscillator is usually a fixed-tuned device with component values determining the frequency. It uses a feedback circuit from the plate to the grid. This feedback circuit consists of three or four R-C sections. The components in these R-C sections are selected to produce a total phase shift of 180 degrees in the voltage arriving at the grid from the plate. In a three-section feedback circuit, each section provides a 60-degree phase shift and, in a four-section feedback circuit, each section provides a 45-degree phase shift.

The amount of phase shift produced across a capacitor is 90 degrees. However, this is useless in a phase-shift oscillator because there is no means to develop a voltage with which to control the grid. To eliminate this undesirable condition, a resistor is connected to the capacitor. This immediately reduces the phase shift from 90 degrees to some angular value, determined by the ratio of capacitive reactance to resistance. In each successive R-C section, a further phase shift occurs. The total phase shift of the voltage arriving at the grid from the voltage on the plate must be 180 degrees.

In a three-section circuit each section provides approximately 60 degrees of phase shift, and in a four-section feedback circuit each section provides approximately 45 degrees of phase shift.

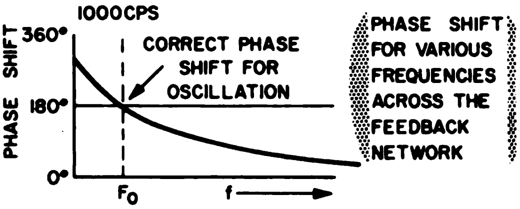


19. —Oscillator feedback network.

The Phase-Shift Oscillator (Continued)

In the oscillator circuit shown in the previous schematic, the ratio of reactance to resistance in each leg will produce a 60-degree phase shift at only one frequency. Therefore, at point A, a voltage will be developed that leads the change in plate voltage by 60 degrees. At point B, the voltage will lead by 120 degrees and at point C, by 180 degrees.

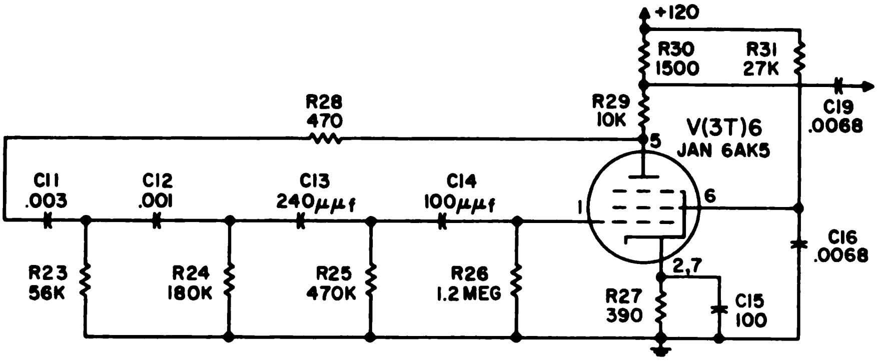
Assuming a positive-plate voltage swing, the grid would be swinging negative due to 180-degree phase shift produced by C1 and R1, C2 and R2, and C3 and R3.



20. —Phase-shift oscillator.

An application of the phase-shift oscillator is found in a fire control radar equipment. This application uses a four-section R-C phase-shifting circuit. The components are selected so that, at the desired frequency, the phase shift of each section will be 45 degrees.

It will be noted in the following schematic that each section differs from the preceding one because the capacitance decreases and the resistance increases. At the desired frequency, the ratio of capacitive reactance to resistance remains the same for each section. Therefore, the phase shift is the same in each section. There are losses in each section of the phase-shifting circuit. To minimize these losses so as to supply sufficient voltage to the grid, each section has a higher resistance as the grid is approached.

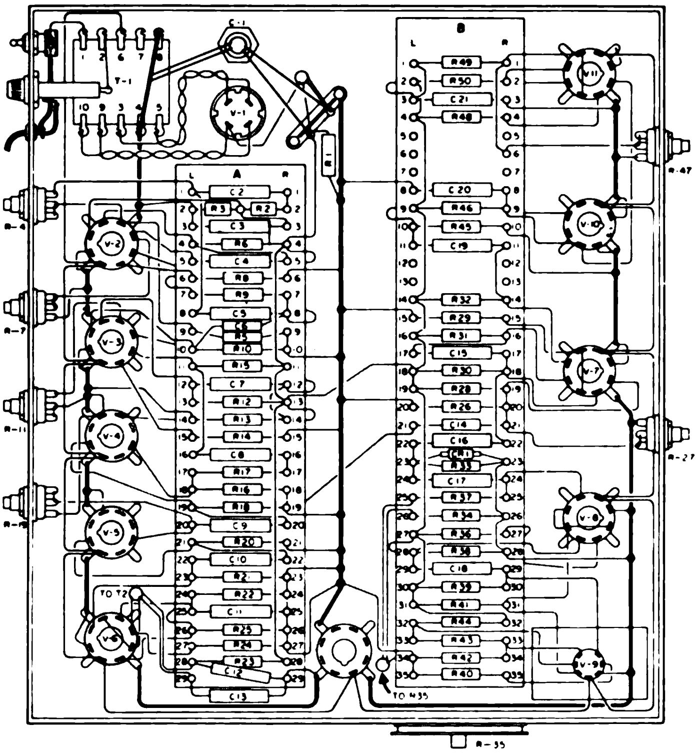


21. —1000-cycle phase-shift oscillator.

AUDIO OSCILLATORS

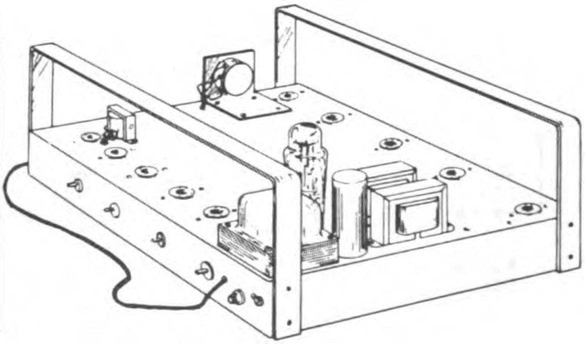
Experiment—Wien Bridge Oscillator Operation

In this experiment, you will check waveforms at various points in the Wien bridge oscillator circuit. You will vary some of the circuit components and note how these variations affect the operation of the circuit. You will check the phase relationship of the signals at various points in the circuit. You will next check the frequency of the generated sine wave by comparing its frequency to the calibrated frequency output of an audio signal generator. Then you will practice trouble shooting the Wien bridge oscillator circuit.



THIS IS WHAT YOU WILL NEED

1. SPECIAL CIRCUITS CHASSIS
2. OSCILLOSCOPE
3. AUDIO SIGNAL GENERATOR
4. MULTIMETER
5. TWO .02-MFD, 600-VOLT, TUBULAR PAPER CAPACITORS
6. 6SN7 TUBE

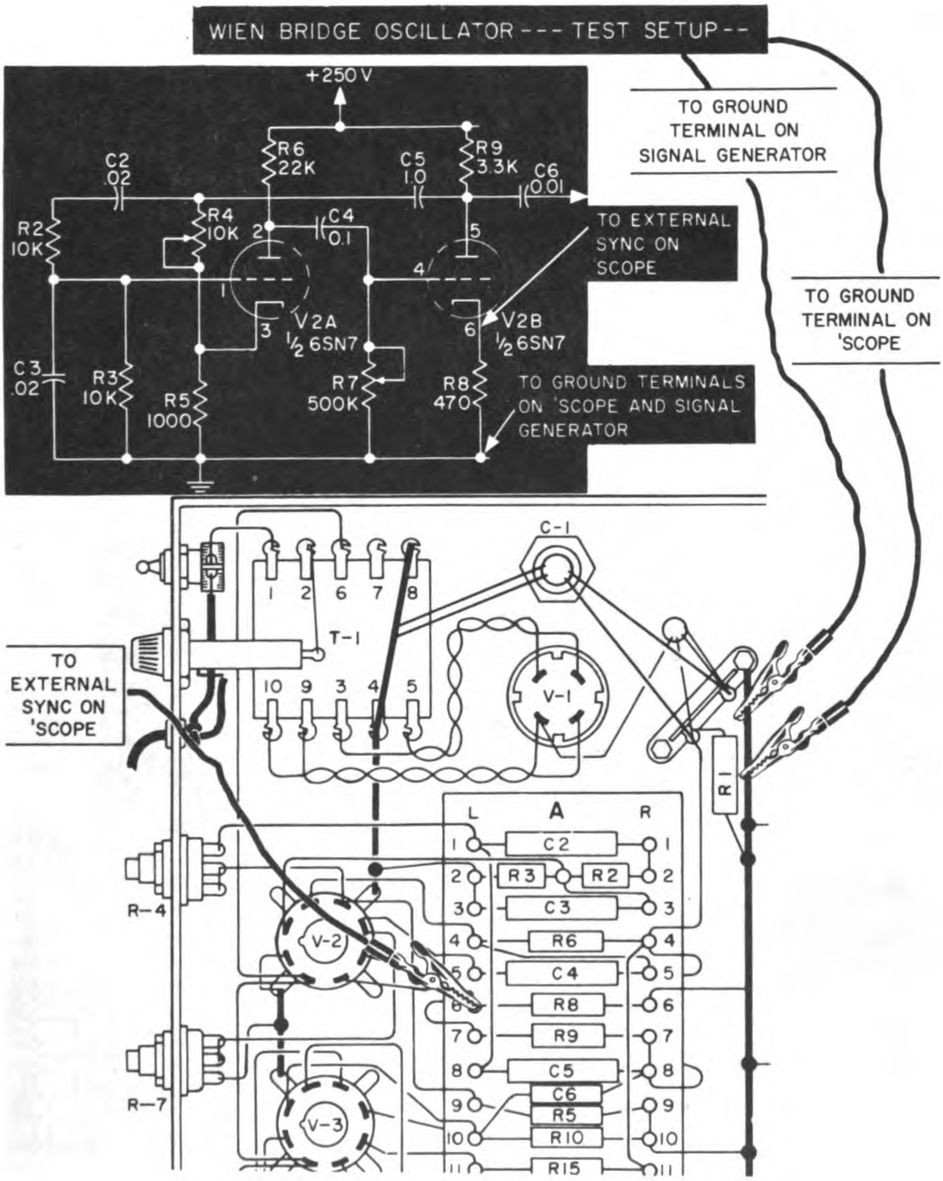


22.—Wien bridge oscillator—test setup.

Experiment—Wien Bridge Oscillator; Test Setup

Connect the ground leads of the 'scope and signal generator to the chassis ground bus, as shown. Attach a test lead from the external sync binding post on the 'scope to lug A-6L, which connects to cathode pin 6 of V2B. Turn on the test equipment, adjusting the 'scope for a focused trace and the signal generator for a calibrated frequency output.

You are now going to check the operation of your Wien bridge oscillator by observing waveforms and checking frequency.



23. —Wien bridge oscillator—test setup.

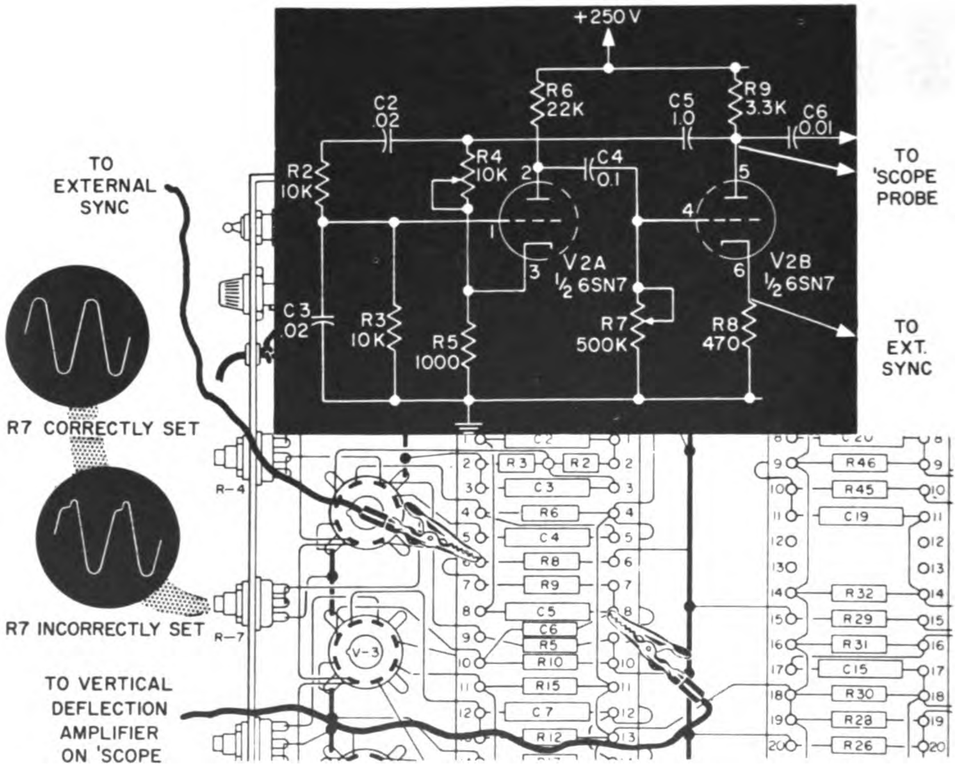
AUDIO OSCILLATORS

Experiment—Wien Bridge Oscillator; Adjusting Circuit

Plug the 6SN7 tube into the V2 socket, attach the 'scope test prod to A-8R (plate of V2B), and turn on the line switch. Set R4 to maximum (clockwise) and adjust R7 for an undistorted sine wave. Set the 'scope frequency controls until two cycles appear. To steady the waveform, vary the sync amplitude control a minimum amount about zero. If too much sync is used, the waveform will appear distorted.

Potentiometer R7, the grid-leak resistor for V2B, together with R6 constitute the load for V2A. By varying R7, you vary this load and, therefore, the gain of V2A. If R7 is too small, the gain of V2A will not be enough to sustain oscillations. If R7 is too large, the gain of V2A increases to the point where the large grid signal drives the tubes into grid current, with resulting distortion to the generated signal. The adjustment of R7 for an undistorted signal is very critical. Vary R7 between its limits and observe the effect on the output, setting it finally for an undistorted output.

Potentiometer R4 is the negative feedback control, the setting of which determines the amount of voltage that is applied across the cathode resistor, R5. The correct setting of R4 is also critical. Decrease R4 and observe that the oscillations get smaller in amplitude and then die out. Readjust R4 for a pure sine wave.

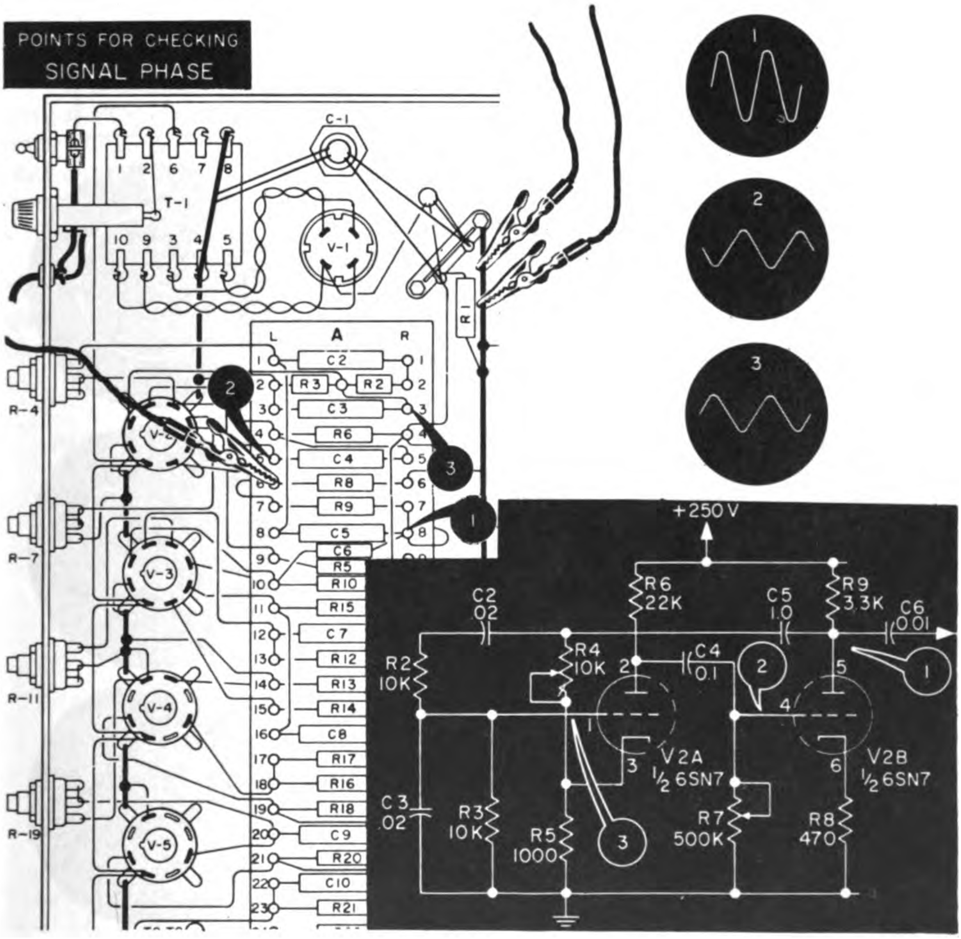


24. —Wien bridge oscillator—adjusting circuit.

Experiment—Wien Bridge Oscillator; Checking Waveforms

You are now going to observe the phase relationships of the signals at various points in the circuit.

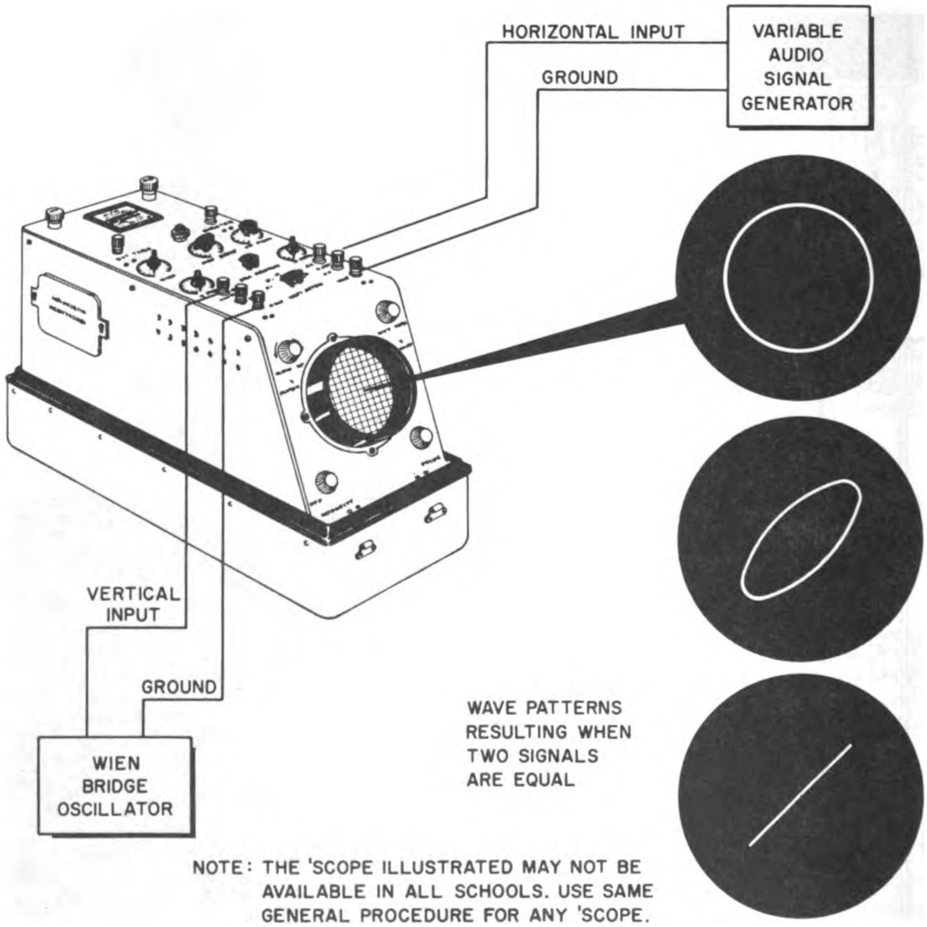
Look at the waveform at point 1, plate pin 5 of V2B (connect probe to A-8R), and adjust the 'scope so that you see a stationary two-cycle sine wave. Note whether the first alternation is positive or negative. Then transfer the probe to point 2, grid pin 4 of V2B (A-5L). You should see a 180-degree phase reversal compared to the plate signal. Next, transfer the probe to point 3, grid pin 1 of V2A (A-3R). Observe that the signal is in phase with the plate signal of V2B. You know, theoretically, that this must be so. The theory of operation of the Wien bridge states that the oscillations will occur only at the one frequency at which the oscillator-section grid signal will be in phase with the plate signal of the amplifier section.



25. —Wien bridge oscillator—checking waveforms.

Experiment—Wien Bridge Oscillator; Checking Frequency

Now you are going to measure the frequency of the signal generated by the Wien bridge oscillator. The general procedure is described on this sheet; the details will be found on the next sheet. To check the frequency, you will connect the probe to the plate of V2B, and connect another probe between the input to the 'scope horizontal amplifier and the signal generator output. Then, with the 'scope and chassis turned on, you will slowly vary the signal generator frequency until a closed loop pattern appears which slowly but continuously changes from a circle, to an ellipse, to a straight line, and back to a circle. At this point, the frequencies of the Wien bridge oscillator and the signal generator are almost equal.


HORIZONTAL INPUT
GROUND
VARIABLE AUDIO SIGNAL GENERATOR
VERTICAL INPUT
GROUND
WIEN BRIDGE OSCILLATOR
WAVE PATTERNS RESULTING WHEN TWO SIGNALS ARE EQUAL
NOTE: THE 'SCOPE ILLUSTRATED MAY NOT BE AVAILABLE IN ALL SCHOOLS. USE SAME GENERAL PROCEDURE FOR ANY 'SCOPE.

26. —Wien bridge oscillator—checking frequency (I).

AUDIO OSCILLATORS

Experiment—Wien Bridge Oscillator; Checking Frequency (Continued)

Connect the test probe to plate pin 5 of V2B (A-8R). Attach a test lead between the high side of the signal generator output and the high side of the 'scope horizontal amplifier input. Turn the signal generator output about half way up and set its frequency to 100 cycles. Adjust the signal generator and the scope horizontal and vertical gain controls until a square pattern of interlaced lines appears on the 'scope screen.

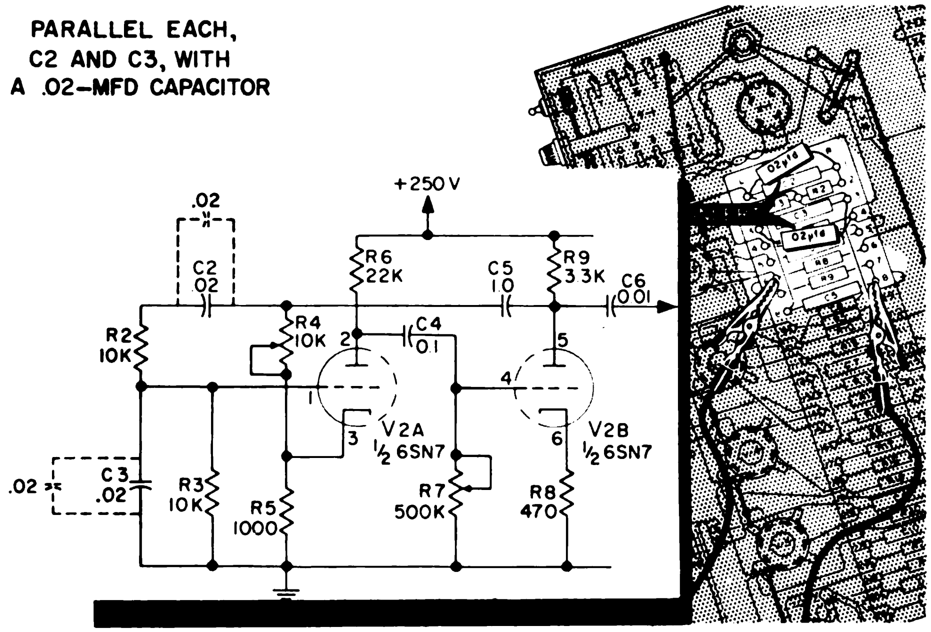
Bring the frequency indicator on the signal generator slowly up the dial, at the same time carefully observing the 'scope screen. The patterns you see will vary widely. When the pattern becomes a closed loop which varies from a circle to an ellipse, the frequency output of the signal generator matches that of the oscillator. Read the frequency of the signal generator dial and write it down.

Next, you will observe the effect on the frequency of the Wien bridge caused by changing the capacitance in the frequency-determining network.

Insert a .02-mfd capacitor in parallel with C2, and another in parallel with C3 (one capacitor connected between A-1L and A-1R, and the other between A-3L and A-3R). Because the new capacitance is double the original capacitance, the generated frequency will be half that of the original frequency.

Check the frequency of the Wien bridge oscillator as you did before. You will see that the new frequency is one-half that of the original frequency. Restore the circuit to normal after completing the frequency check.

PARALLEL EACH,
C2 AND C3, WITH
A .02-MFD CAPACITOR



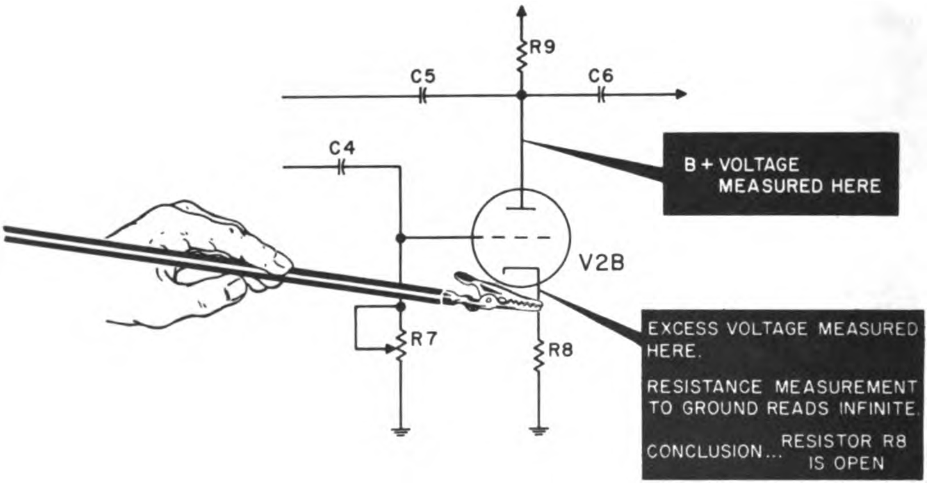
27. —Wien bridge oscillator—checking frequency (II).

Experiment—Wien Bridge Oscillator; Trouble Shooting

Trouble shooting the Wien bridge oscillator circuit is no different than trouble shooting any amplifier circuit. It involves (1) isolating the trouble to the defective stage by signal tracing, (2) tube substitution, (3) voltage-checking tube pins to determine defective circuit, and (4) resistance checking defective circuit to isolate defective component.

If, for example, step (1) has isolated the defective stage and step (2), tube substitution, does not clear up the difficulty, step (3), voltage checks, must be tried next.

If the cathode resistor is open, a d-c voltage check at the plate will reveal a voltage equal to the B+ voltage. This reading immediately tells you that no current is flowing through the resistor, the cause of which is either no tube emission or an open in the cathode d-c return to ground. You know the tube is not at fault, because you replaced it. Therefore, the trouble is limited to the cathode d-c ground return. If you connect the high impedance of the d-c voltmeter between the cathode and ground, the cathode circuit to ground is completed through the voltmeter, which will then give a high reading. You, therefore, know that the cathode circuit is open and a resistance check (step 4) will localize the break.

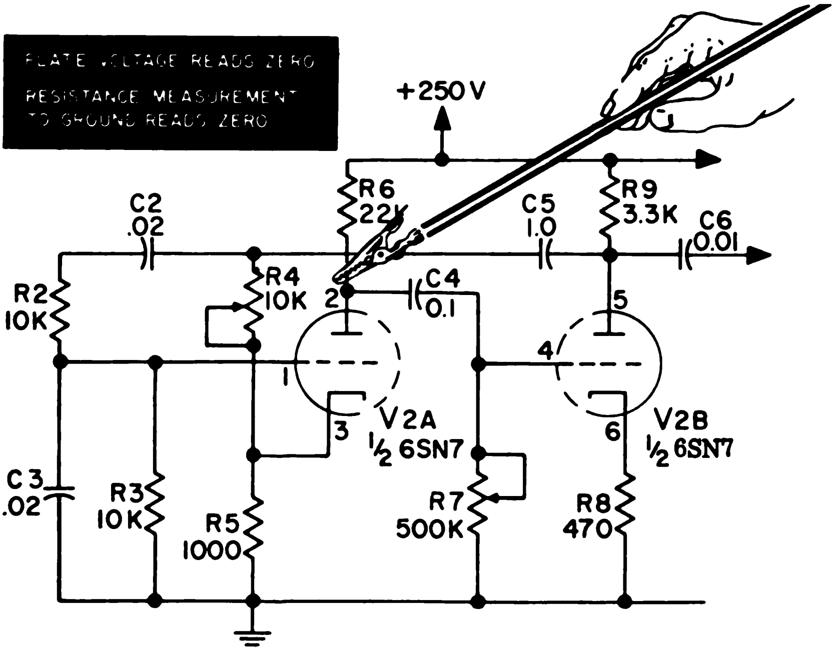

R9
C5
C6
C4
B + VOLTAGE MEASURED HERE
V2B
R7
R8
EXCESS VOLTAGE MEASURED HERE.
RESISTANCE MEASUREMENT TO GROUND READS INFINITE.
CONCLUSION... RESISTOR R8 IS OPEN

28. —Trouble shooting (I).

Experiment—Wien Bridge Oscillator; Trouble Shooting (Continued)

If a d-c voltage check at the plate of a triode tube reads zero volts, it probably means that the point of no voltage is shorted to ground or the voltage-dropping resistor to B+ is open.

For example, if the plate voltage of V2A measures zero volts to ground, you immediately suspect that the plate end of R6 is shorted to ground, or that R6 is open. If the plate end of R6 is shorted to ground, there will be excessive current through this resistor. The resistor will be overheated and will burn out. Therefore, if in addition to the zero voltage symptom, you see that the plate resistor is charred, you can look for a short at the plate end of R6. A resistance check from the plate of V2A to ground, with power turned off to the chassis, would confirm your suspicion. If R6 were open, there usually would be visual indications of this casualty.



29. —Trouble shooting (II).

A shorted coupling capacitor will put a positive d-c voltage on the grid of the next stage. Loss of signal and damaged components will be the results of this type of casualty.

An open coupling capacitor will reveal itself by not passing a signal from the plate of one stage to the grid of the next. This defect can be found by signal tracing, in which the signal generator output is applied first to one side of the capacitor and then to the other. If the signal shows up in the one case and not in the other, the capacitor is open. A fast way to check for an open in a capacitor is to parallel it with another capacitor simply by touching the leads of the suspected capacitor with the leads of the good capacitor. If the trouble is thus eliminated, the original capacitor has definitely been proved to be open.

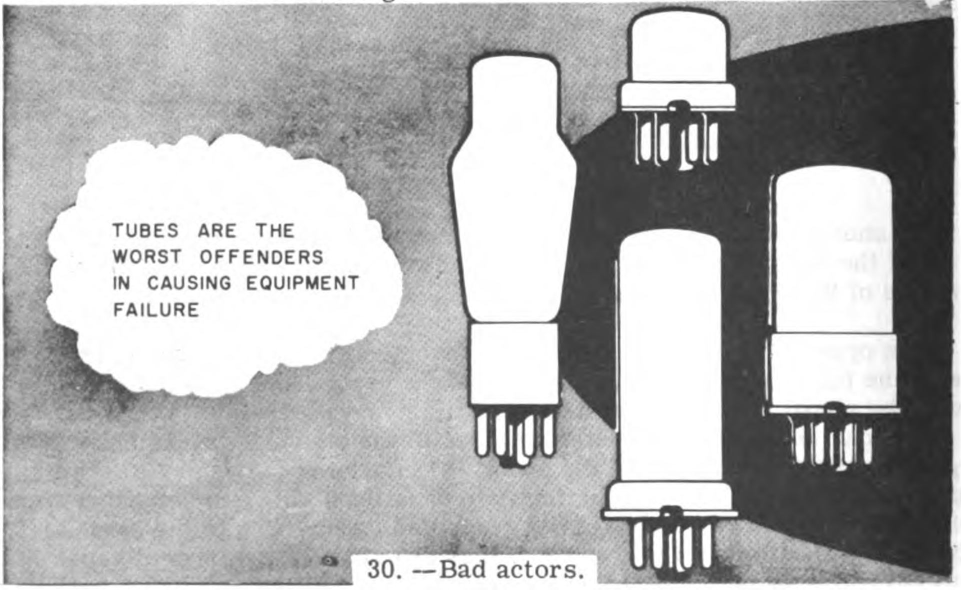
Experiment—Wien Bridge Oscillator; Trouble Shooting (Continued)

You will now insert a number of troubles into the Wien bridge circuit and you will follow a given procedure in localizing these troubles. You are to do this so that you may get the necessary practice in following a logical trouble shooting procedure.

Before inserting any casualty, check that your Wien bridge is oscillating by properly adjusting your controls (R4 and R7). In actual practice, when a casualty occurs to electronic equipments, the first step is to insure that power is available and operational controls are set properly.

Trouble No. 1—Remove the 6SN7 tube from its socket and replace it with an open-filament tube, which your instructor will hand you. Apply power to your circuit as well as to all test equipment. Connect your 'scope test prod to the plate (A-7R) of V2B. Of course, you see no output. You immediately suspect the tube to be bad. The filaments of most glass tubes can be checked by visual inspection. Some glass tubes are opaque and the filaments cannot be seen. In this type it is usually possible to determine that the filaments are intact by feeling the heat of the glass envelope. Dangerous voltages are present on the shell of some metal tubes. The shell of a metal tube should be touched with extreme caution. It is safer to de-energize the equipment and check the tube filament circuit using an ohmmeter or a tube checker. Replace the tube with your good tube and you will see the oscillator break into oscillations once again.

This experiment has illustrated for you the very important fact that the majority of all troubles in electronic equipment are caused by bad tubes. Tubes over a period of time develop the following defects: (1) filaments burn out, (2) emission drops, and (3) adjacent elements short. Any one of these tube defects will always disable a portion of an electronic equipment, if not the entire equipment. Remember, therefore, after a trouble has been isolated to a particular stage by signal tracing, first suspect the tubes and make sure they are good before proceeding with extensive trouble shooting.


TUBES ARE THE WORST OFFENDERS IN CAUSING EQUIPMENT FAILURE

30. —Bad actors.

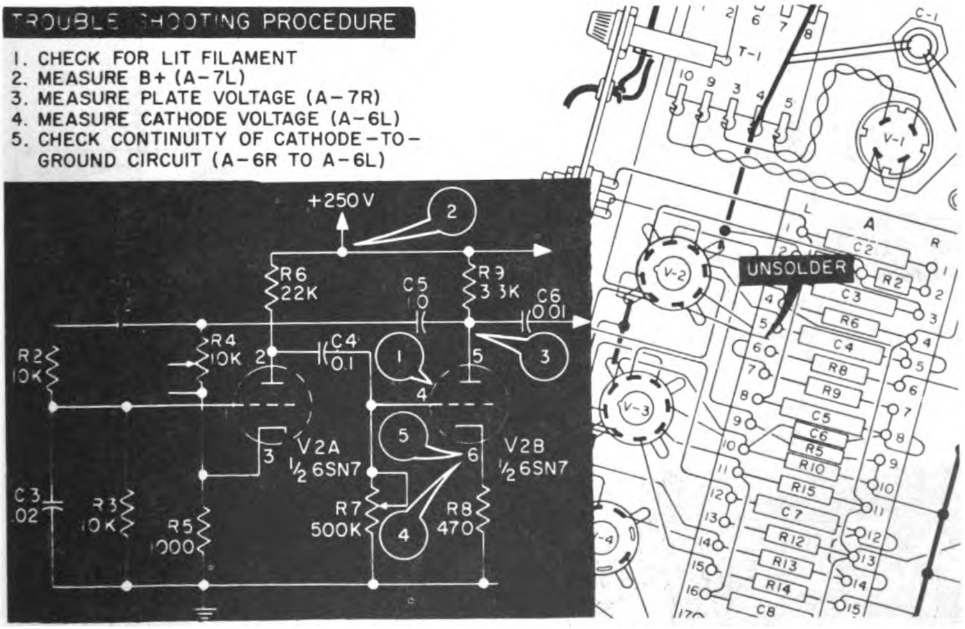
Experiment—Wien Bridge Oscillator; Trouble Shooting (Continued)

Trouble No. 2—Disconnect cathode resistor R8 from the cathode of V2B by disconnecting the resistor from lug A-6L. This simulates an open cathode resistor. Place the 'scope probe at the plate of V2B (A-7R). Again there is no output. You first suspect the tube. (For precautions to be observed in determining if the filament circuit of a tube is good, refer to trouble No. 1 on the opposite page.) The glow of the filament or the heat of the shell will indicate that the filament circuit is complete. To be perfectly sure in actual practice that it is not the tube, you would replace it with a good one.

Next, set up your voltmeter to measure d-c volts on the 500-volt range and check the B+ voltage (A-7L) (step 2). The voltage is normal at about +250 volts. Check the plate voltage (step 3) of V2B (voltmeter probe to A-7R). The voltage you measure is the same as the B+ voltage, and you are assured that the tube is not conducting, because of an open in the external d-c path between plate and cathode.

Now check the d-c voltage between cathode and ground (step 4) of V2B (voltmeter probe to A-6L). Observe that the voltage reading is much higher than normal. This means that the voltmeter has completed the return path between cathode and ground and, therefore, an open must exist somewhere between cathode and ground.

Turn power off to the chassis before making resistance measurements. You are now ready to check the continuity of the cathode-to-ground d-c path (step 5). Set up your ohmmeter and measure continuity between lug A-6R and lug A-6L (across R8). You read infinite resistance, which means that the connection is open. Resolder the resistor lead back on lug A-6L.


TROUBLE SHOOTING PROCEDURE

1. CHECK FOR LIT FILAMENT
2. MEASURE B+ (A-7L)
3. MEASURE PLATE VOLTAGE (A-7R)
4. MEASURE CATHODE VOLTAGE (A-6L)
5. CHECK CONTINUITY OF CATHODE-TO-GROUND CIRCUIT (A-6R TO A-6L)

31. —Trouble shooting (III).

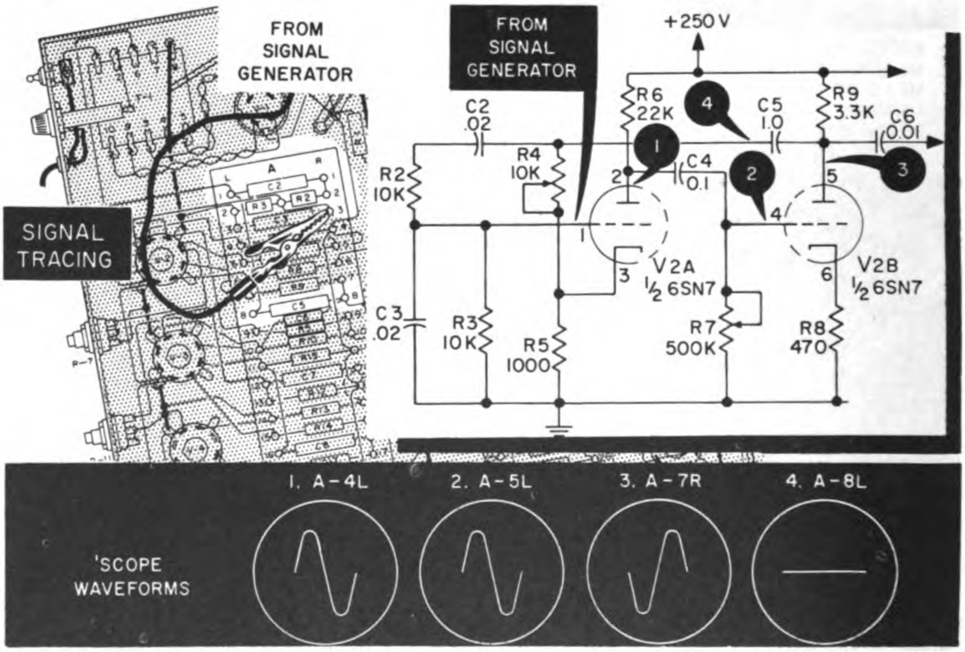
Experiment—Wien Bridge Oscillator; Trouble Shooting (Continued)

Trouble No. 3—Disconnect coupling capacitor C5 from the plate of V2B by unsoldering the capacitor lead connected to A-8R, thus simulating an open coupling capacitor. Place the 'scope probe on A-7R (plate of V2B). Again there is no output. Proceed to trouble shoot the circuit in the same manner as you did before, checking in the following order: (1) filaments, (2) B+ voltage, (3) plate voltage. The third, check of plate voltage, should reveal to you that the V2B section is conducting because of the voltage drop in R9. Next, check for conduction in the V2A section by measuring plate voltage (voltmeter probe to A-4L). The reading indicates to you that the V2A section is also conducting.

There is no output from the oscillator; however, V2A and V2B are conducting. It appears likely that the casualty is in the coupling circuit between V2A and V2B, or it is in the feedback circuit.

At this point, signal tracing with a signal generator and 'scope may help. First, open the feedback loop by unsoldering C2 and R4 from A-1L. Connect the high side of the signal generator to the grid of V2A (A-3R) and adjust its frequency to the Wien bridge frequency. Switch the scope to internal sync. Connect the 'scope to the plate of V2A (A-4L), the grid of V2B (A-5L), and the plate of V2B (A-7R). You observe a signal at each one of these points. To check the continuity of the feedback loop, connect the 'scope to the V2A side (A-8L) of coupling capacitor C5. The signal disappears and, therefore, you conclude that C5 is open. Resolder C5 to A-8R and C2 to A-1L.

In actual practice, if trouble is eliminated by paralleling a suspected open capacitor with a good one, the original must have been open.



32. —Trouble shooting (IV).

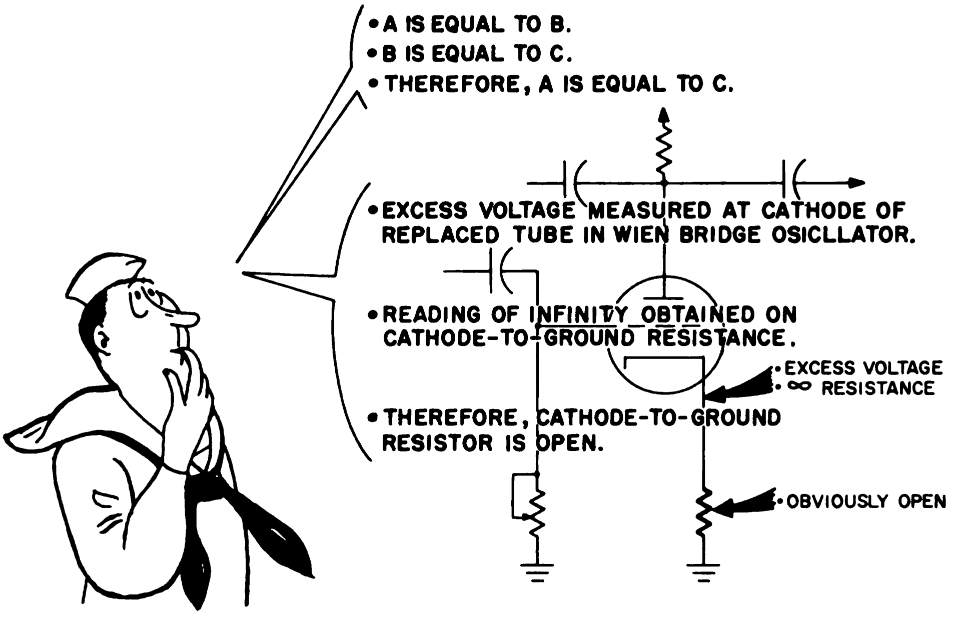
Experiment—Wien Bridge Oscillator; Trouble Shooting (Continued)

The instructor will now assign two of you to insert troubles into each other's Wien bridge oscillator circuits. Before you insert the trouble, check with your instructor to make sure he approves your selection. If he does, insert the trouble and try not to make it too apparent. The types of troubles you should insert are a bad tube, an open resistor or capacitor, a shorted resistor (and, in rare cases, a shorted capacitor), an open fuse, a bad rectifier, or an open lead.

If you decide to short a component, you must choose one with care. You should not, for example, short a coupling capacitor because, in so doing, the grid side of the capacitor becomes highly positive, with possible resulting damage to the tube. Also, if the grid leak resistor is of low value, the short will result in a large current flow through the plate-load resistor, which may burn up as a result.

When you think you have found the trouble, consult with your partner. If you are correct, make the necessary repairs. If time permits, you will put additional trouble in each other's circuits. Remember that the idea of this trouble-shooting experiment is to get you to develop a logical method of servicing, as used by all efficient technicians.

As you trouble shoot your chassis, take notes of the resistances, voltages, and waveforms that you obtain. After several steps have been taken, analyze your notes. They will often indicate a course of action which will enable you to locate the faulty component. Development of this note-taking habit will aid you in trouble shooting the extensive circuits utilized in fire control radars.


• A IS EQUAL TO B.
• B IS EQUAL TO C.
• THEREFORE, A IS EQUAL TO C.
• EXCESS VOLTAGE MEASURED AT CATHODE OF REPLACED TUBE IN WIEN BRIDGE OSICLLATOR.
• READING OF INFINITY OBTAINED ON CATHODE-TO-GROUND RESISTANCE.
• THEREFORE, CATHODE-TO-GROUND RESISTOR IS OPEN.
• EXCESS VOLTAGE
• ∞ RESISTANCE
• OBVIOUSLY OPEN

33. —The magic of trouble shooting lies in using a logical procedure (I).

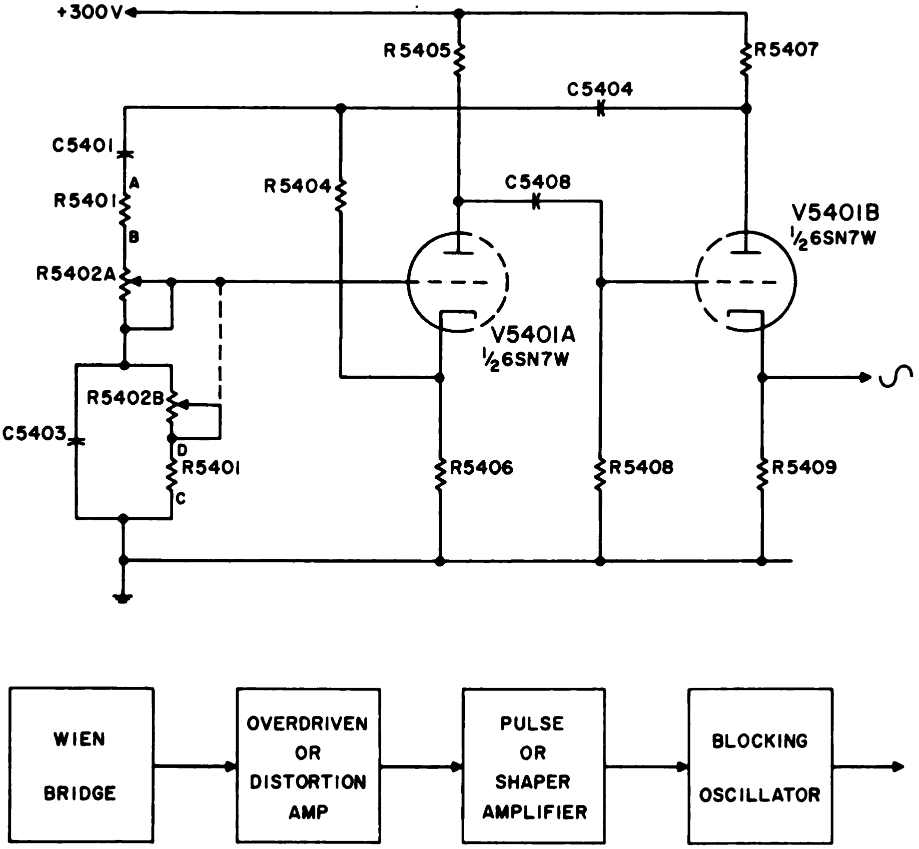
Application—Wien Bridge Oscillator

Shown below is the schematic of a Wien bridge oscillator that is used in a fire control radar.

In this oscillator, the positive feedback is adjustable so that the frequency can be controlled through a selected frequency range. Since this frequency is different from that used in the oscillator with which you have worked, the circuit components are of different values.

Notice that by adjusting R5402 the relationship of resistance in both parts of the positive feedback circuit is modified by the same amount and in the same direction. This maintains the required balance in the bridge circuit but varies the frequency selective character of the feedback circuit.

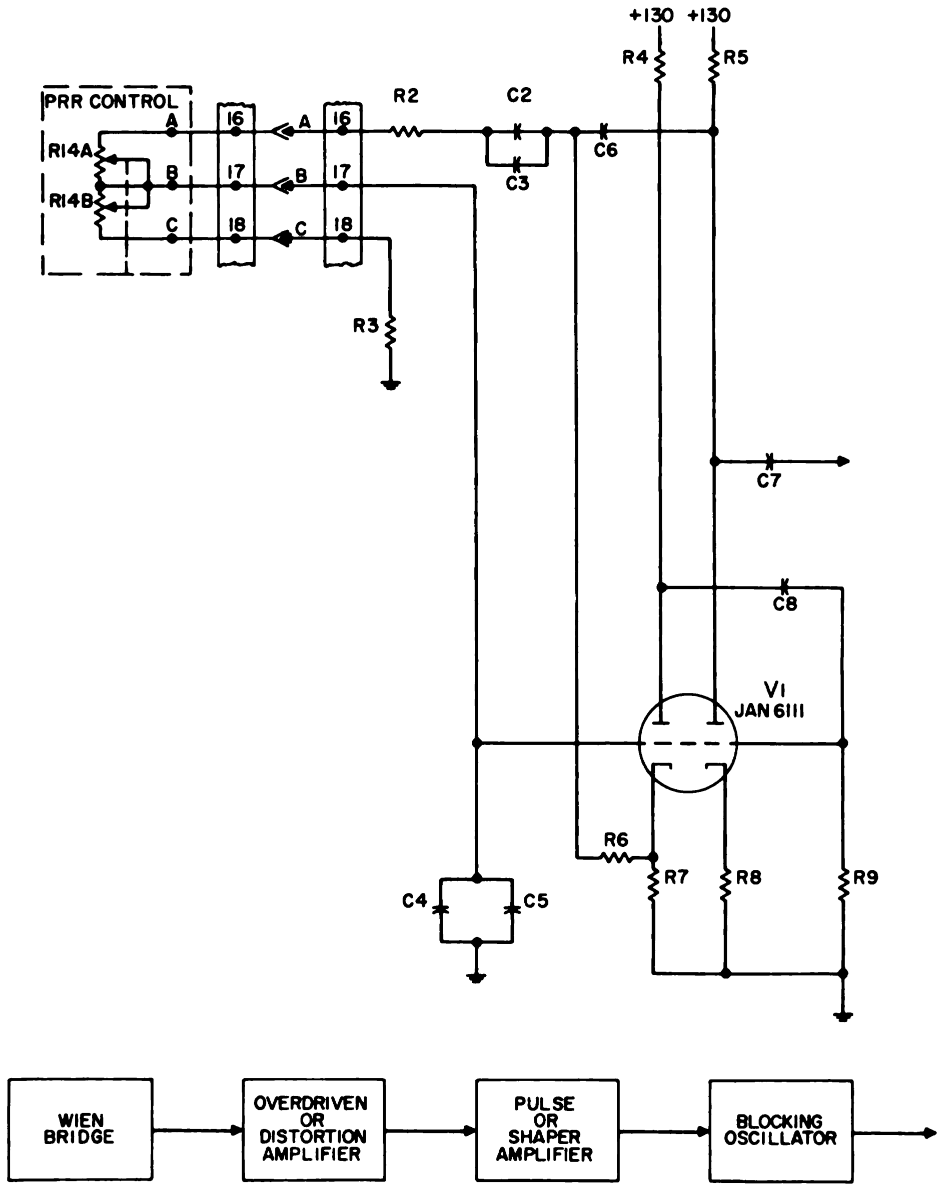
By observation, you should have no trouble in relating this circuit to the one with which you have been working.



34. —Radar Equipment Mark 35 Wien bridge oscillator.

Application—Wien Bridge Oscillator (Continued)

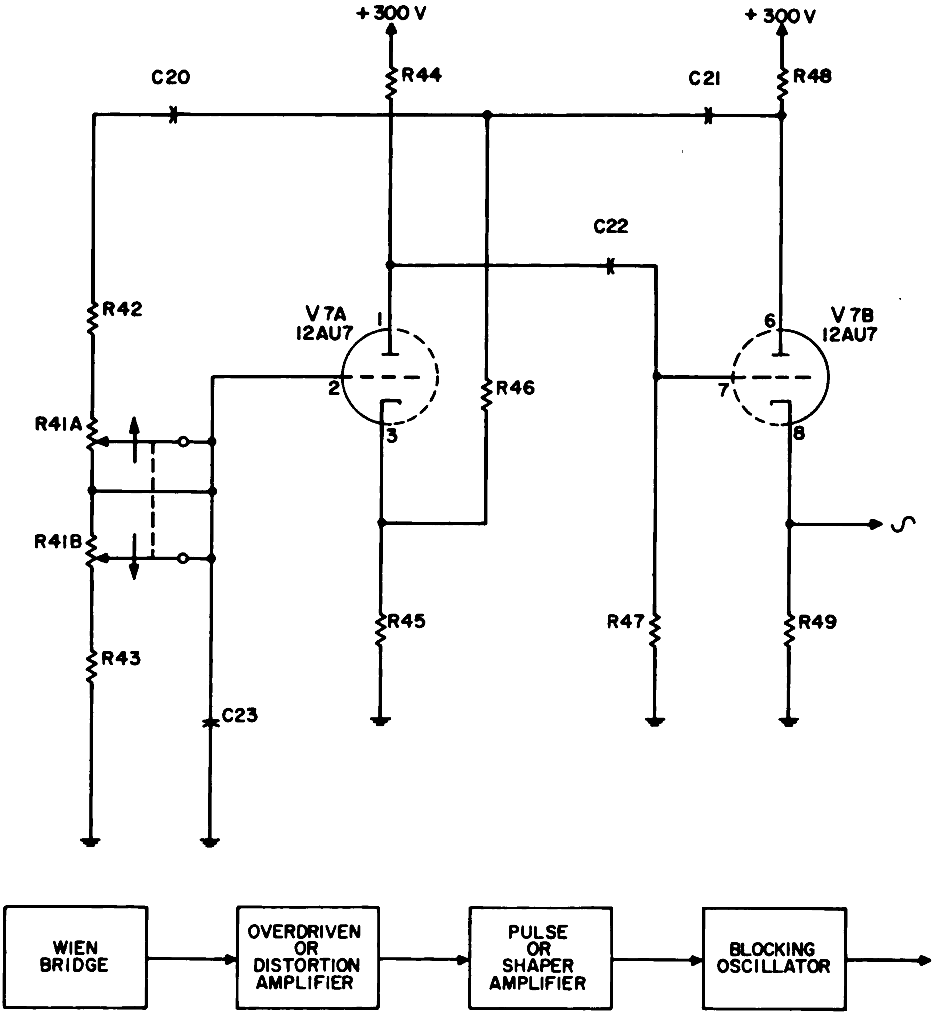
On this page is another Wien bridge oscillator which is used in a fire control radar. It should be easy for you to identify the component parts of the positive and negative feedback circuits. Notice once again that the variable components are in the positive feedback circuit for the control of frequency.



35. — Radar Set AN/SPG-50 Wien bridge oscillator.

Application—Wien Bridge Oscillator (Continued)

Here again is another application of a Wien bridge oscillator used in another fire control radar.



36. — Radar Set AN/SPG-48 Wien bridge oscillator.

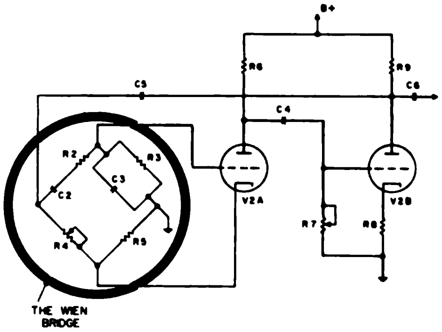
Have you noticed that in each application the positive feedback circuit can be varied as desired to obtain the required range of operating frequencies?

Observation of the block diagrams indicates that the output of the Wien bridge is applied to the same series of circuits in each of the listed applications.

Review

In this topic, you learned about the Wien bridge and phase-shift oscillators. These circuits differ from conventional oscillators with tuned circuits by using a resistor-capacitor, selective-frequency feedback network. This network allows only one frequency at the output of an amplifier to be fed back to the input in phase with the input signal and of sufficient amplitude to sustain oscillations. These circuits provide a high degree of frequency stability.

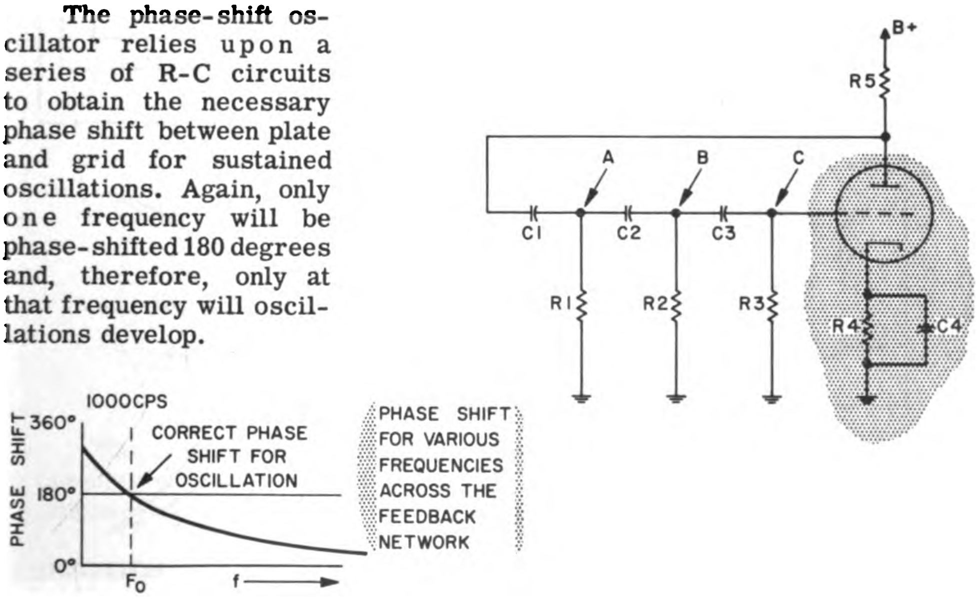
The frequency-selective network of the Wien bridge oscillator consists of R2 and C2, and R3 and C3. They are selective because they produce the proper reactance at only one frequency. This reactance is such that the proper ratio of positive feedback voltage to negative feedback voltage will appear between the grid and cathode of V2A to sustain the oscillations. The ratio must be such that the positive feedback exceeds the negative feedback.



37. Wien bridge oscillator network.

The Wien bridge oscillator is used in some fire control radars to generate the pulse repetition frequency. In these applications, the positive feedback circuit may be varied by ganged potentiometers to change the frequency of the oscillator and the pulse repetition rate of the radar. The negative feedback remains fixed. In the three applications, the basic circuits are the same. Circuit components have different values and were selected to obtain the desired frequencies.

The phase-shift oscillator relies upon a series of R-C circuits to obtain the necessary phase shift between plate and grid for sustained oscillations. Again, only one frequency will be phase-shifted 180 degrees and, therefore, only at that frequency will oscillations develop.


B+
R5
A
B
C
C1
C2
C3
R1
R2
R3
R4
C4
1000CPS
360°
180°
0°
PHASE SHIFT
CORRECT PHASE SHIFT FOR OSCILLATION
F0
f
PHASE SHIFT FOR VARIOUS FREQUENCIES ACROSS THE FEEDBACK NETWORK

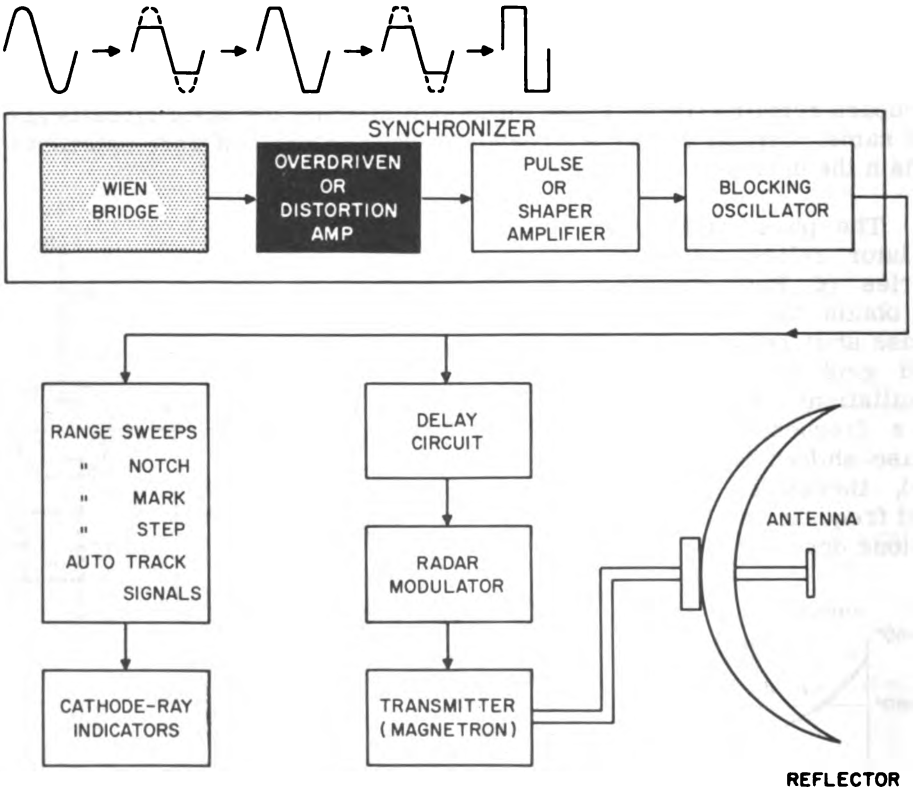
38. — Oscillator feedback network.

TOPIC 3: LIMITING CIRCUITS—AMPLIFIER TYPE

General Uses

A limiting circuit is a shaping circuit that removes the positive, the negative, or both extremes of an input signal. Such a circuit is also often known as a "clipper." Limiters, or clippers, have a number of applications in radar. When a square wave is desired and only a sine wave is available, both the positive and negative peaks may be cut off. The resulting signal, when further amplified and reclipped, ends up as an almost perfect square or rectangular wave. Other applications use limiters to remove completely the positive or negative swing of the input signal.

There are two general groups of limiting circuits used in fire control radar equipments—those using amplifier tubes and those using diodes. In this topic, only those circuits based upon amplifier tubes will be discussed. The diode limiters are reserved for a later topic, as their functions in radar circuits are somewhat different from the amplifier-type limiters. The limiting circuits to be described in this topic include saturation and cut-off limiting. An amplifier circuit in which saturation limiting is used in conjunction with cut-off limiting to produce a rectangular or square wave from a sine wave is generally known as an overdriven amplifier.



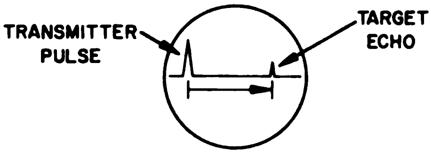
39. —Forming square waves by limiting action.

LIMITING CIRCUITS—AMPLIFIER TYPE

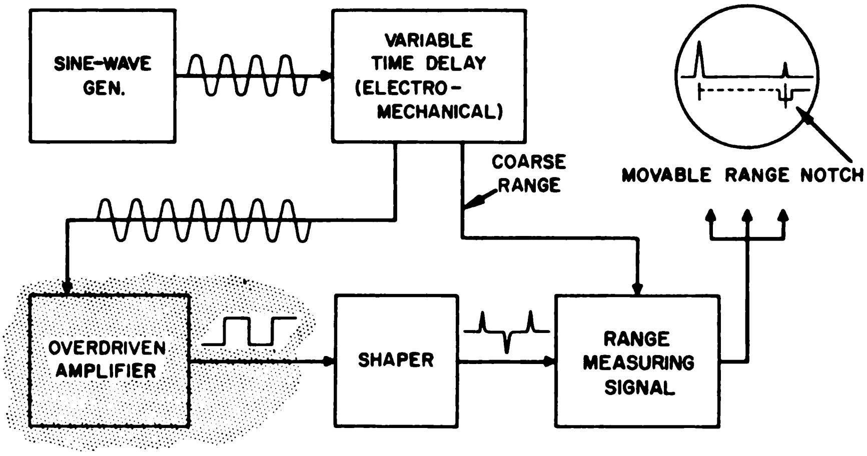
Uses of Overdriven Amplifiers

In many radar systems, a sine wave is developed as an accurate timing wave. In order to retain proper timing relationships, it is often necessary to use this sine wave as the source of signal voltages for other circuits in the radar. However, a sine wave does not possess all the necessary requirements for development of pulses and triggers for use in other circuits. This is the point at which the overdriven amplifier is extremely useful, as it can distort the sine wave in one or two tube stages so that a square or rectangular wave is developed. A square wave can be reshaped readily into a voltage pulse or trigger for use elsewhere in the system, and still have a definite time relationship to the sine wave that was used to develop the trigger.

Overdriven amplifiers are found in most of the Range Determination Circuits of fire control radar equipments. You also may encounter them in other radar circuits.



WHAT IS THE RANGE?



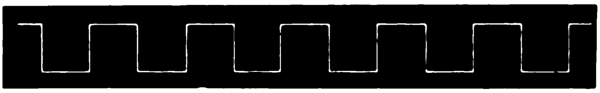
40. —The overdriven amplifier.

The overdriven amplifier is used to reshape a sine wave into a rectangular or square wave of the same frequency, and usually of greater amplitude.

LIMITING CIRCUITS—AMPLIFIER TYPE

What an Overdriven Amplifier Is

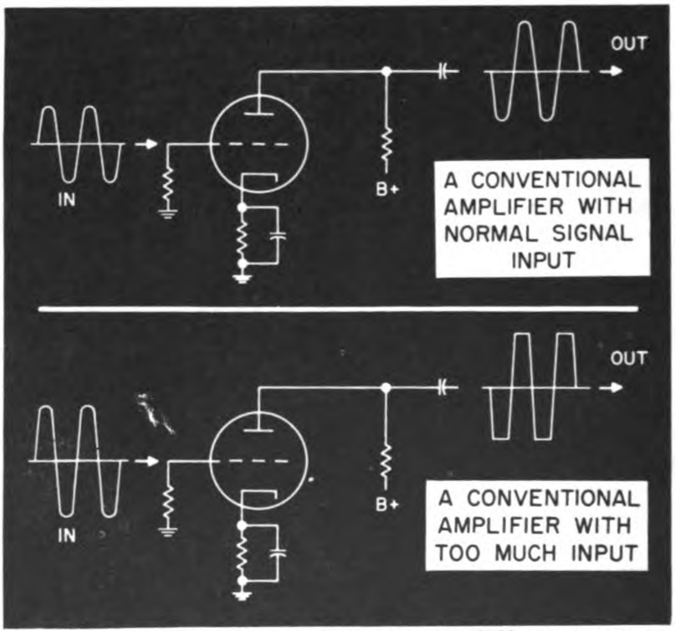
In the study of radar, you are going to come across voltage waveforms which are new and different to you. One of the most important of these new waveforms is the square or rectangular wave.



41. —The square wave.

As you go on through the study of special circuits and, after that, the radar systems themselves, you will see the many uses that the square wave has.

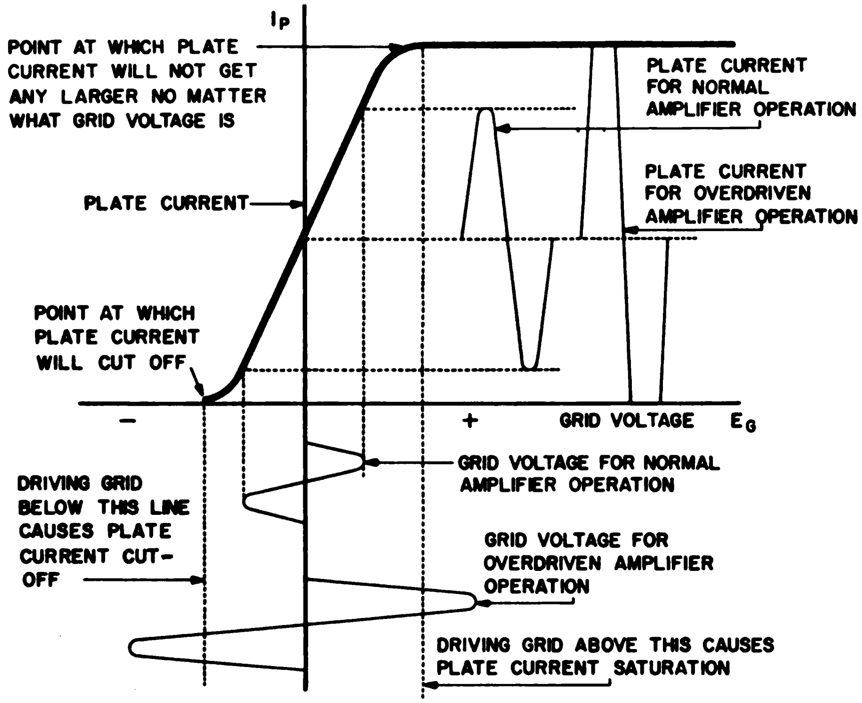
The overdriven amplifier is one particular type of limiting or clipping circuit that can be used to produce a square-wave output. It is an ordinary amplifier with a grid on which a large sine-wave input is impressed. In the output, the peaks of this sine wave have been clipped off and the sides of the sine wave made steeper. The frequency of this square wave is the same as that of the sine-wave input.


OUT
IN
B+
A CONVENTIONAL AMPLIFIER WITH NORMAL SIGNAL INPUT
OUT
IN
B+
A CONVENTIONAL AMPLIFIER WITH TOO MUCH INPUT

42. —Comparison of amplifiers with different inputs.

The overdriven amplifier is an amplifier with an input large enough to overdrive the stage and cause the output to be distorted into a square wave. It may be considered as a combination of two types of limiters—the cut-off limiter and the saturation limiter. The cut-off limiter limits the positive output peak and the saturation limiter limits the negative output peak.

Details of Overdriven Amplifier Operation



43. —Graph showing operation of overdriven amplifier.

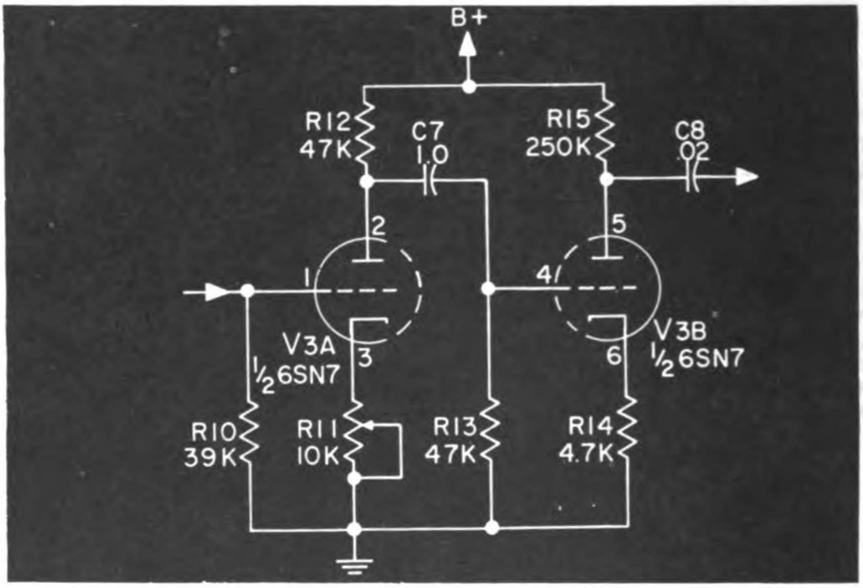
The positive input peak, applied to the grid of the overdriven amplifier, causes the plate current in the circuit to increase until the point is reached at which no more plate current will flow, no matter how positive the grid voltage becomes. This is known as plate-current saturation. You know from your early work with amplifiers that the plate voltage drops as the plate current increases. You also know that the plate voltage remains steady while the tube is saturated, but that it will increase when the input signal and, hence, the plate current falls off.

The negative peak of the input signal drives the grid negative and reduces the plate current until the tube is cut off; that is, no plate current is flowing. Under these conditions, you know that the plate voltage increases as the plate current decreases. While the tube is cut off, the plate voltage remains steady at the value of the power supply voltage and when the tube comes back into conduction, the plate voltage decreases once again.

Saturation limiting holds the negative output signal peak to some low value. Cut-off limiting holds the positive output signal peak to the value of B+.

Details of Overdriven Amplifier Operation (Continued)

In the experiment that will follow shortly, you will work with an overdriven amplifier. You will observe the operation of your overdriven amplifier by driving it with the output of the Wien bridge oscillator and viewing with the oscilloscope the voltage waveforms at various points within the circuit.

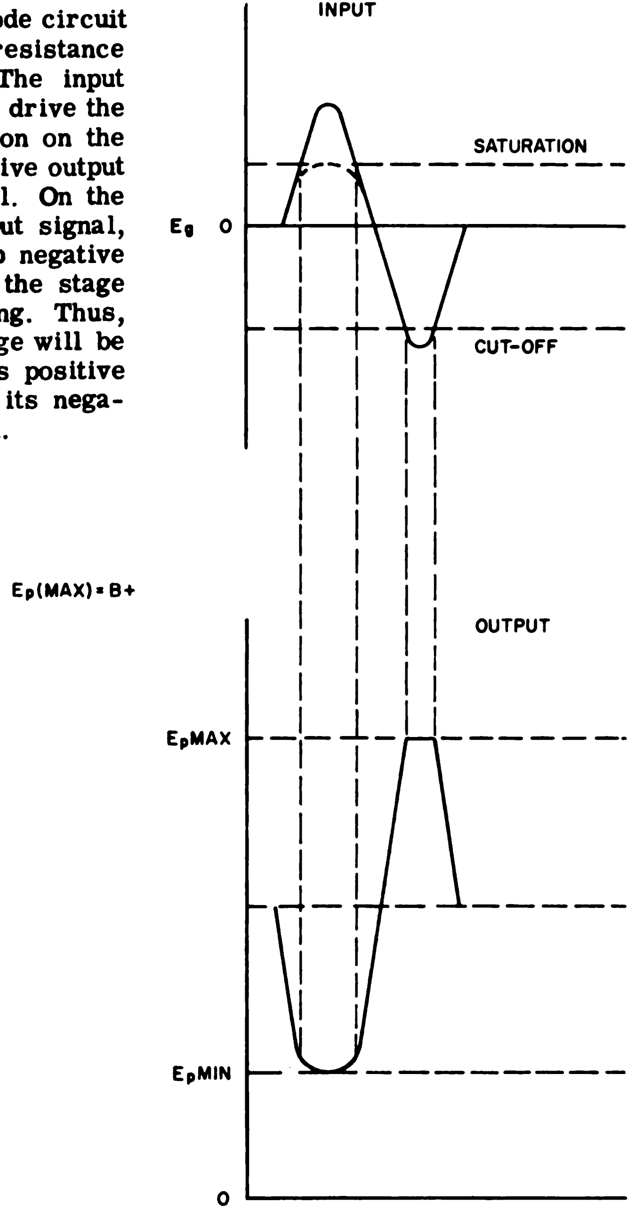


44. —You will check a two-stage overdriven amplifier.

So that the output square wave will have fairly steep sides without the use of an excessively large input, the overdriven amplifier is divided into two stages. The variable cathode resistor in the first stage allows you to vary the bias on this stage and to observe this stage functioning as a cutoff limiter only.

Details of Overdriven Amplifier Operation (Continued)

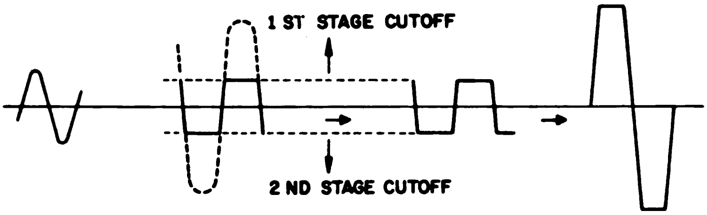
The output voltage of the Wien bridge oscillator is fed to the grid of the first stage. Assume first that the potentiometer in the cathode circuit is set so that there is no resistance in the cathode circuit. The input signal is strong enough to drive the grid into the cut-off region on the negative swing. The positive output is limited to the B+ level. On the positive swing of the input signal, grid current will develop negative bias and prevent driving the stage into full saturation limiting. Thus, the output of the first stage will be a distorted sine wave; its positive peaks will be clipped and its negative peaks will be rounded.



45. —Grid and plate voltage curves showing positive and negative limiting of output signal.

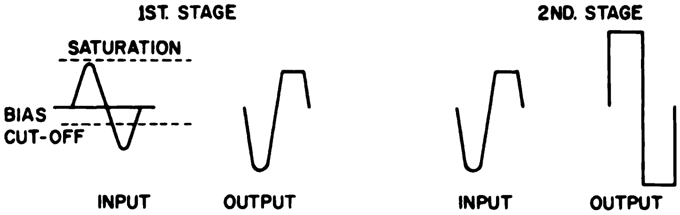
Details of Overdriven Amplifier Operation (Continued)

The output from the first stage is fed to the grid of the second stage. This overdrives the second stage and the sides of the waveform become much steeper, since nearly all of the curved portion of the original sine wave has either been saturated or cut off by this time.



46. —Overdriven amplifier (I).

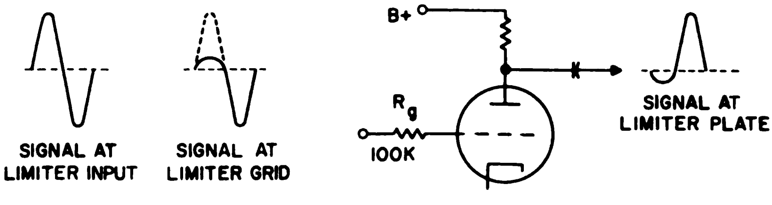
Now assume that the potentiometer in the cathode of the first stage is turned up, so that there is resistance in the circuit. This means that the grid is not operating at zero volts, but rather at some negative value, due to the cathode bias. The operating point of V3A shifts down the E_g-I_p curve, so that it takes a stronger signal to drive the tube to saturation, but the tube can be more easily cut off.



47. —Overdriven amplifier (II).

There is another type of limiting circuit that is used in fire control radar equipments. It is the grid-current limiter and it functions to remove the positive peak from the input signal. The identifying feature of this type of limiting circuit is the series grid resistor.

On the positive peaks of the input signal, grid current will flow and the signal voltage at the grid is reduced to a lower value. Even though the positive signal is amplified in the tube, it is hardly noticeable in the plate circuit. The negative half of the input signal receives full amplification and the signal available at the plate is one with the negative portion of the sine wave removed.



48. —Grid current limiter circuit.

LIMITING CIRCUITS—AMPLIFIER TYPE

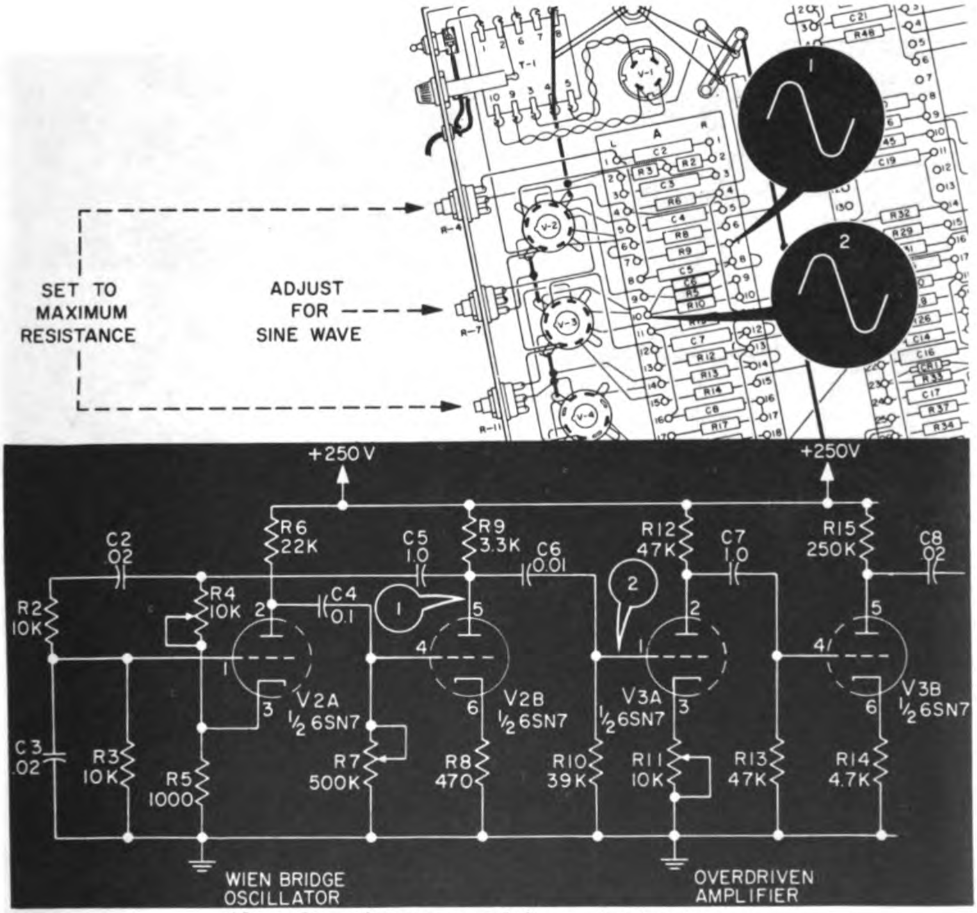
Experiment—Test Setup

In this experiment, you will see how the overdriven amplifier, operating a cut-off and near saturation limiting, converts the sine-wave output of the Wien bridge oscillator into a square wave. You will check the signal at various points and note how varying a certain component affects the operation of the circuit. Then you will practice trouble shooting the overdriven amplifier.

For this experiment, you will require a 'scope and a multimeter, as well as an additional 6SN7 tube.

Insert the 6SN7 tube in the V3 socket, and apply power to the chassis and 'scope. Connect the 'scope ground lead to a chassis ground bus, and the probe to point 1, plate pin 5 of V2B (A-7R). With R4 and R11 at their maximum resistance setting, slowly vary R7 until you get an undistorted sine-wave picture.

Now move the 'scope probe to point 2, grid pin 1 (A-10L) of the first section of the overdriven amplifier, V3A. Observe that the waveform here is the same as on the plate of V2B, because the plate and grid are separated only by a coupling capacitor.



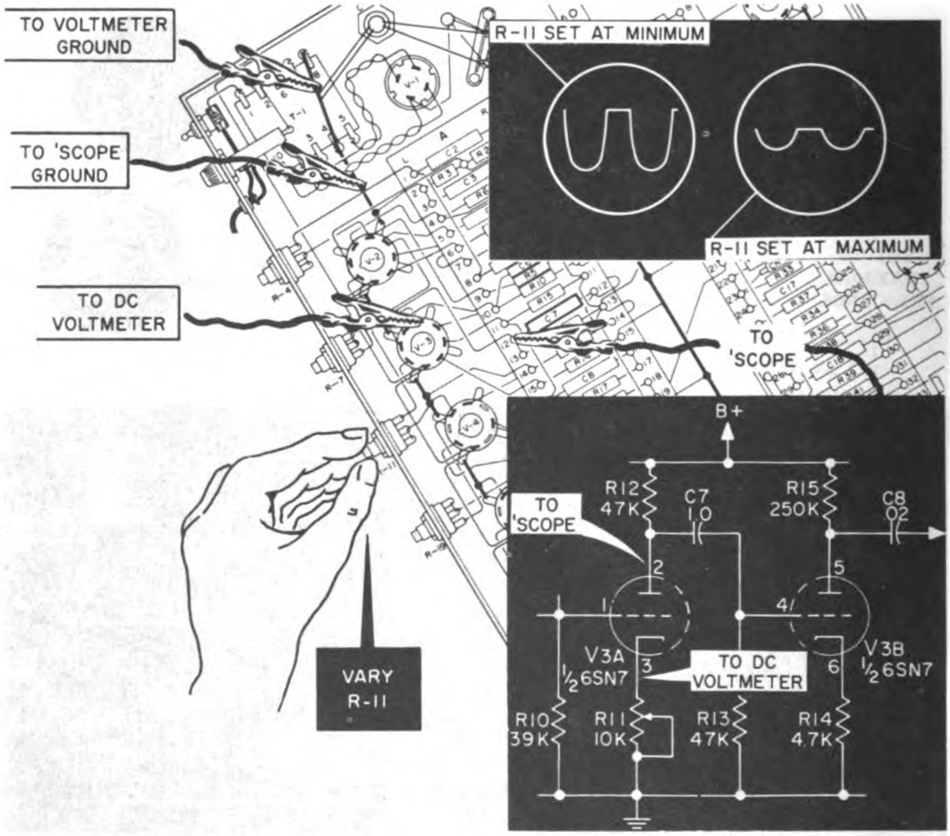
49. —Overdriven amplifier—test setup.

LIMITING CIRCUITS—AMPLIFIER TYPE

Experiment—Checking Waveforms

Place the 'scope test probe on plate pin 2 (A-12L) of the V3A section of the overdriven amplifier. Now vary cathode potentiometer R11 over its entire range and note how the waveform is affected. Observe that, at minimum resistance, the waveform is cut off at the top. The negative portion of the input signal will drive the tube to cut-off, but the positive portion will not drive it into saturation, as this portion results in grid current and develops grid bias. With R11 at maximum resistance, V3A is operating close to cut-off and, therefore, a negative-going signal will more easily cut the tube off, while a positive-going signal will be amplified.

To measure the average bias, set R11 at maximum and connect the plus lead of the d-c voltmeter to cathode pin 3 (minus lead to ground). Note that it is about 10 volts. Then the tube has a negative 10-volt bias on its grid, which is near cut-off. The flat portions of the waveform correspond to the time intervals when the negative-going grid signal drives the tube into cut-off. At these intervals, the plate voltage is constant and equal to B+. The sinusoidally varying, negative-going portions of the waveform correspond to the time intervals when the positive-going grid signal drives the grid voltage into the less negative region. The tube is now amplifying and develops in its plate circuit the negative-swinging plate voltage, with the waveform which you see on the 'scope.



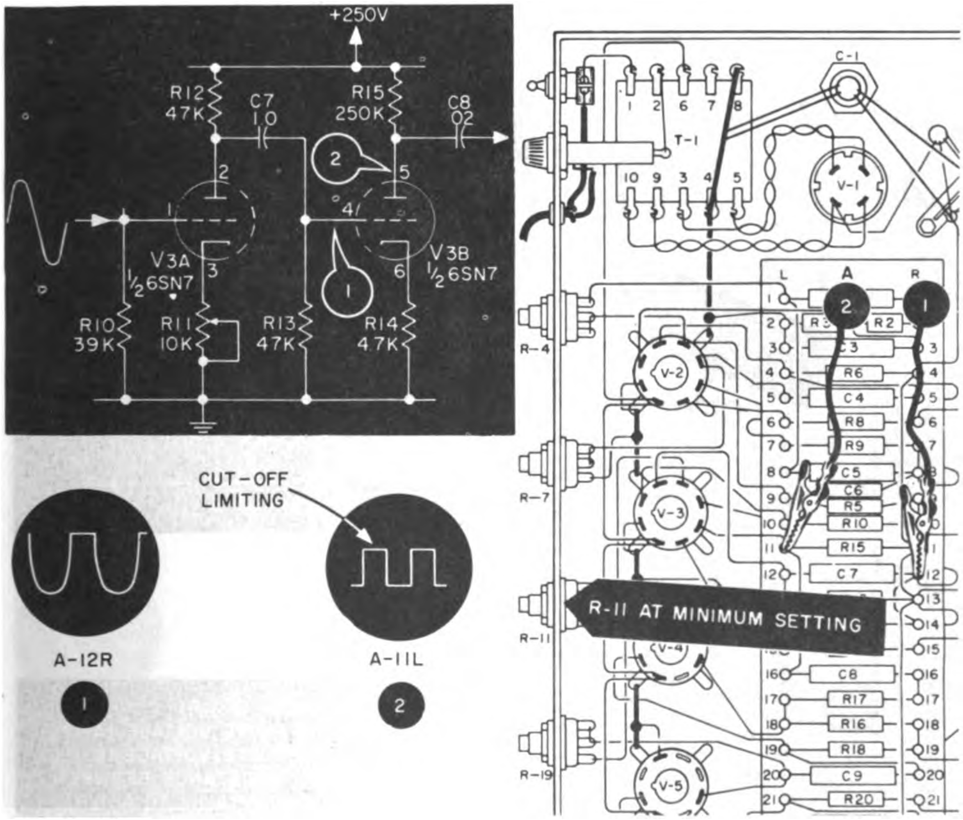
50. —Overdriven amplifier—checking waveforms (I).

Experiment—Checking Waveforms (Continued)

To check operation of the second section of distortion amplifier, V3B, place 'scope lead on pin 5 (A-11L). Set R11 at minimum resistance and note that the waveform is a square wave. Now check the input to V3B at A-12R. Notice that the negative portion is not quite flat, while the positive portion is square due to the cut-off limiting in V3A. The negative portion is large enough to drive V3B into cut-off; thus, a square wave is available at pin 5 of V3B. The square wave is produced by cut-off limiting in both sections of V3.

Now place the 'scope probe on the plate (A-11L) of V3B and increase the resistance of R11. Notice that the positive-going portion of the waveform is flat, indicating cut-off limiting, due to the negative grid swing.

The slight rounding of the negative portion of the waveform in the plate of V3B, when R11 is at maximum resistance, is due to the large cathode resistance of V3A which reduces its gain. Thus, the negative-going grid of V3A just barely reaches cut-off. This produces some rounding of the positive portion of the signal at the grid of V3B. The magnitude of this signal is insufficient to drive V3B into saturation. Therefore, some slight rounding of the negative portion of the waveform is seen in the plate of V3B.



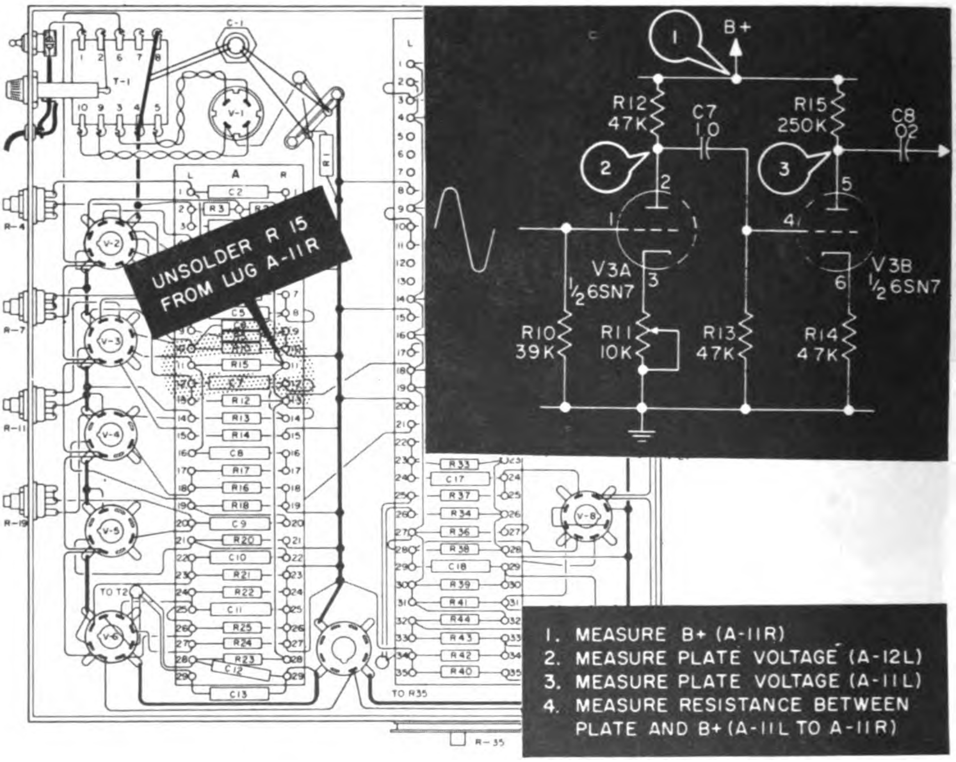
51. —Overdriven amplifier—checking waveforms (II).

Experiment—Trouble Shooting

The procedure used to trouble shoot an overdriven amplifier is exactly the same as that used to trouble shoot a conventional amplifier. Very briefly, this procedure involves isolating the trouble to a defective stage (usually by signal tracing) and then isolating the defect to a particular component in that stage by voltage and resistance measurements.

As with the Wien bridge oscillator, you will first insert specified defects into your circuit. Then, by following a logical trouble-shooting procedure as outlined for you on these sheets, you will see how easily you can arrive at the suspected trouble source.

Trouble No. 1—Remove B+ from the plate of V3B by disconnecting R15 from lug A-11R, thus simulating an open plate-load resistor. Connect the 'scope probe to pin 5 of V3B (A-11L). The symptom is no output from the overdriven amplifier. Next, insure that the Wien bridge is oscillating. You now suspect V3, replace it with a good tube, and the trouble remains. Next, check point 1 (B+), which is normal. Since there are only two stages, you can quickly check their plate voltages to gain a clue to the possible trouble. At point 2, the plate voltage reading of V3A (A-12L) is normal but, at point 3, the plate voltage reading of V3B (A-11L) is zero. You immediately conclude that the tube is not conducting, due to an open between the plate and B+. Turn off the power to the chassis; then check the resistance between the plate and B+. An infinite reading points to an open plate-load resistor. Reconnect R15 to A-11R.



UNSOLDER R 15 FROM LUG A-11R

1. MEASURE B+ (A-11R)
2. MEASURE PLATE VOLTAGE (A-12L)
3. MEASURE PLATE VOLTAGE (A-11L)
4. MEASURE RESISTANCE BETWEEN PLATE AND B+ (A-11L TO A-11R)

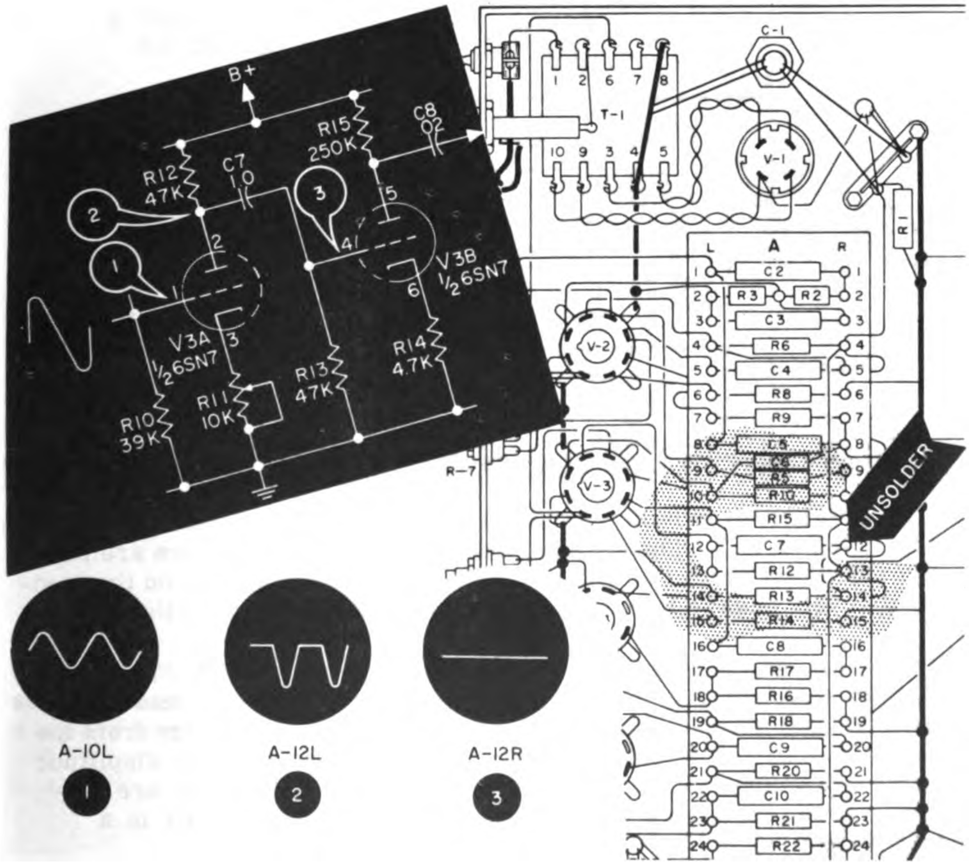
52. —Overdriven amplifier—trouble shooting (I).

Experiment—Trouble Shooting (Continued)

Trouble No. 2—Simulate an open coupling capacitor between V3A and V3B by disconnecting C7 from A-12R. Proceed to trouble shoot the circuit by signal tracing with a 'scope. The signal source is the Wien bridge oscillator and, therefore, a signal generator is not required.

Connect the 'scope to point 1, the grid of V3A (A-10L), and note the presence of a waveform. Next, connect the 'scope to point 2, the plate of V3A (A-12L), and note the presence of a signal. From here, connect the 'scope to point 3, the grid of V3B (A-12R), and note the absence of a signal. At this point, stop and study the circuit. What will produce the symptoms you have observed? C7 could be open or R13 could be shorted, and the symptoms would be the same. In normal trouble shooting, the casualty would not be so evident and you probably would want to parallel C7 with a known good capacitor. If the symptom remained, the next logical step would be to secure power to the chassis and measure the resistance of R13. Resolder C7 to A-12R.

You will now pair off and insert troubles into each other's circuits—anywhere in the Wien bridge oscillator or overdriven amplifier. Check with your instructor before you insert a trouble and remember to use a logical trouble-shooting procedure to facilitate finding the trouble.

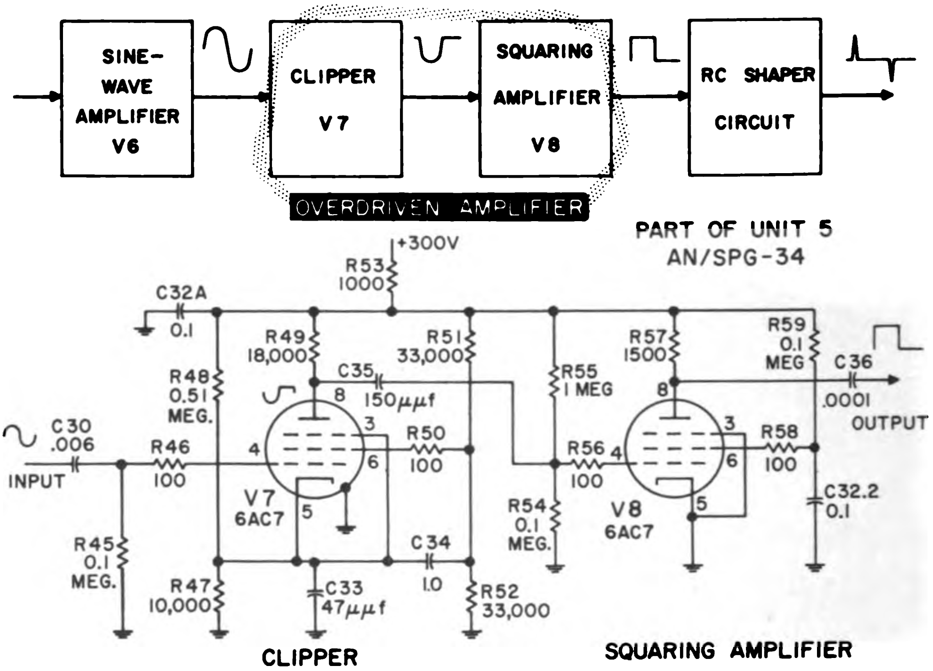


53. —Overdriven amplifier—trouble shooting (II).

Applications—Overdriven Amplifiers

There are a number of applications of the overdriven amplifier in fire control radar equipments. You will find several variations of this circuit and some of them will vary considerably from the overdriven amplifier that you have studied. You will find other names used for this circuit. Some of these names are "Squaring Amplifier," "Distortion Amplifier," "Clipper Amplifier," and "Slicer."

The overdriven amplifier that you studied in the special circuits chassis made use of cut-off limiting in two stages to produce a square wave from a sine wave. The first application of this circuit is from Radar Set AN/SPG-34. This application uses two tube stages to produce a square wave from a sine-wave input. The schematic of this circuit is given in the diagram below. Note the similarities to, and the differences from, the circuit you have studied.



54. —Overdriven amplifier—application (I).

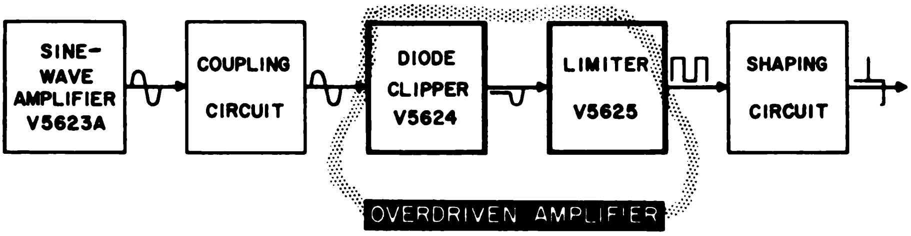
V7 is held near cut-off by a positive cathode bias obtained from voltage divider R48 and R47. The negative half-cycles of the sine wave are eliminated, since they drive the tube to cut-off. The tube conducts on the positive half-cycle and the inverted, clipped waveform appears in the plate.

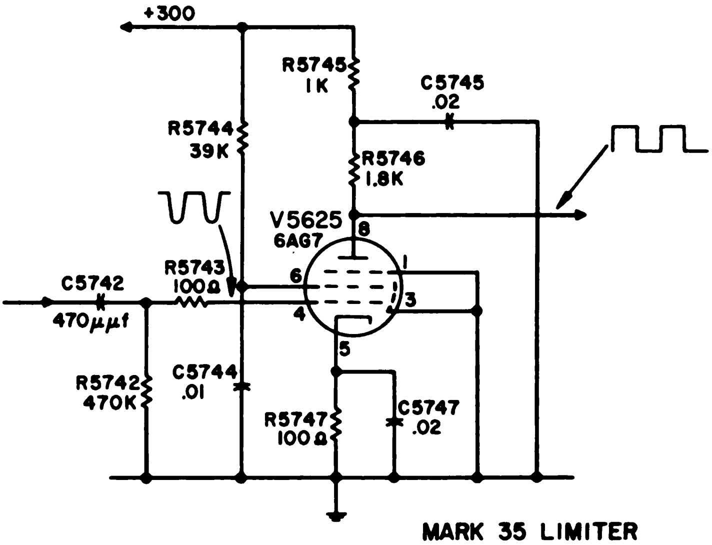
The next step in preparing timing pips takes place in V8. The control grid of V8 is biased at about +30 volts by voltage divider R55 and R54, between B+ and ground. The negative half-cycles of the voltage from the plate of V7, which still have sinuform peaks, have sufficient amplitude to drive V8 below cut-off. The square, positive half-cycles are amplified. Thus, the voltage appearing in the plate of the tube is a square wave.

Applications—Overdriven Amplifiers (Continued)

Below is shown another application of an overdriven amplifier used in a fire control radar.

In this case, a clipping circuit is used preceding the overdriven amplifier. Under these circumstances, the overdriven amplifier is biased so that the unclipped portion of the sine wave will drive the tube to cut-off or saturation. For example, if the clipper removes the positive portion of the sine wave, then the overdriven amplifier will be biased so that the remaining (negative) portion will drive it to cut-off. This action produces the desired square or distorted wave.



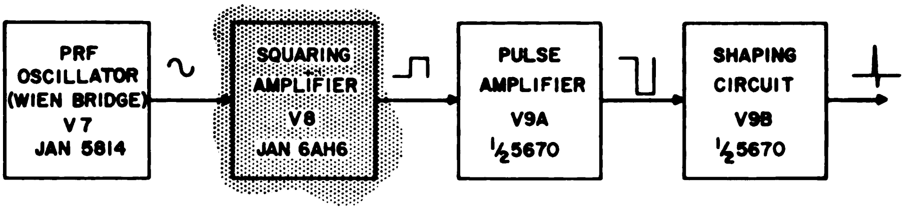


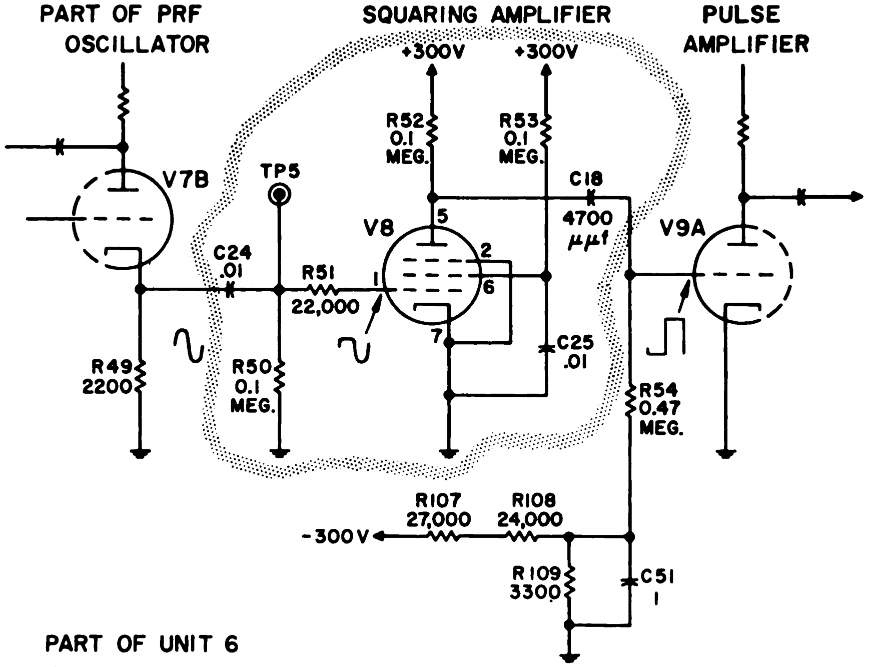
55. —Overdriven amplifier—application II.

The first stage in the distortion circuit is a diode which clips the incoming sine wave. This diode is connected so that the negative halves of the sine wave are applied to the grid of the following pentode, V5625. This stage (distortion amplifier) has a high gain and its output voltage approaches a square wave.

Applications—Overdriven Amplifiers (Continued)

Another example of a circuit that is used to shape a sine wave into a square wave is given below. This circuit uses grid-current limiting and cut-off limiting. You will note that this tube is referred to as a Squaring Amplifier.


PRF OSCILLATOR (WIEN BRIDGE) V7 JAN 5814
SQUARING AMPLIFIER V8 JAN 6AH6
PULSE AMPLIFIER V9A ½5670
SHAPING CIRCUIT V9B ½5670

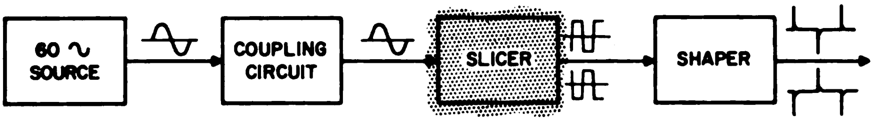


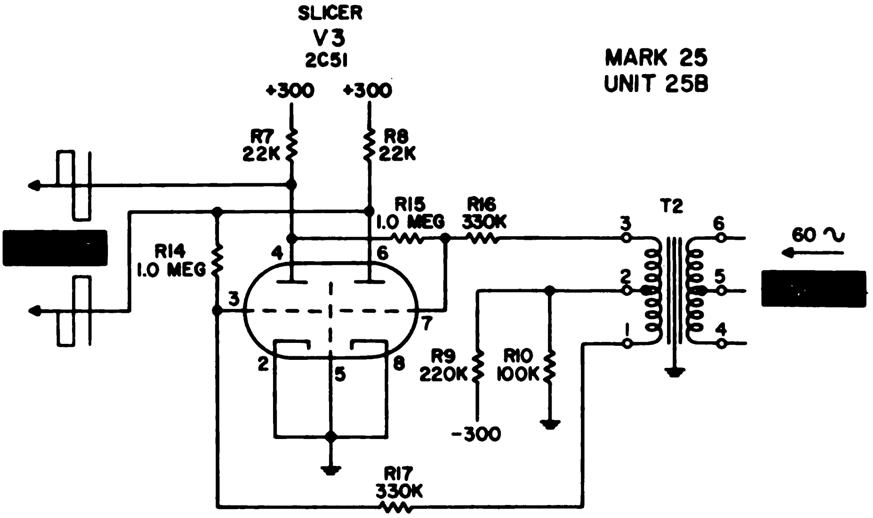
56. —Overdriven amplifier—application III.

The Squaring Amplifier, V8, has as its input the sine-wave output of the Wien bridge oscillator. The positive portions of the input signal are clipped by the grid-limiting action produced by the grid current flowing through resistor R51. The negative portions of the input signal drive the grid voltage below cut-off and the voltage at the plate of V8 rises to the B+ level. This develops a signal across the plate-load resistor R52 that is essentially a square wave.

Application—Overdriven Amplifiers (Continued)

A fourth application of overdriven amplifiers is shown below. This circuit will be found in the regulating circuits of a power supply used in a fire control radar.





57. —Overdriven amplifier—application IV.

In this application, V3, in its static condition, is just above cut-off. The output voltage of T2 is applied to grids 3 and 7 of slicer V3. Because of positive feedback, V3 has a very high gain. When grid 7 is positive, grid 3 is negative. The resulting positive voltage developed at plate 4, due to the negative voltage on grid 3, is fed back through R15 to grid 7, increasing its positive voltage (the action being regenerative). However, the high value of grid resistor R16 results in grid-current clipping. The resulting voltage appearing on plate 6 is a square wave, because the grid clipping permits only a small portion of the positive-input sine wave to appear in the output. On the negative half-cycle, grid 7 goes toward cut-off and, at this time, the positive portion of the sine wave on grid 3 develops a negative-going voltage in plate 4. This is coupled to pin 7, driving the 6-7-8 section into cut-off. The action for a complete cycle of signal voltage is the same in the 2-3-4 section. Thus, each half of V3 performs grid-current limiting and cut-off limiting. However, one-half of the tube is 180 degrees out of phase with the other half at all times.

In the particular system in which this tube is encountered, it is referred to as a Slicer, since it slices the top and bottom portions off the sine wave.

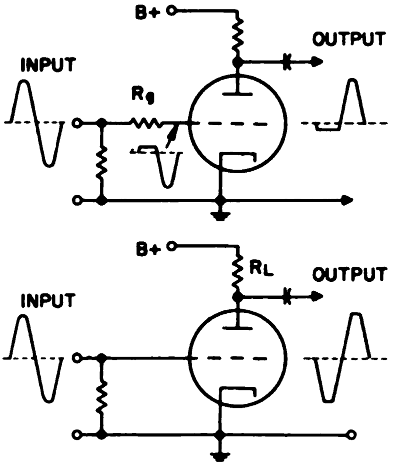
LIMITING CIRCUITS—AMPLIFIER TYPE

Review

In this topic, you learned about limiting or clipping circuits using amplifier tubes. Their most common application in radar is as pulse-shaping circuits. They function by clipping a portion of the positive or the negative signal, or both portions. The amount to be clipped can be varied by the design. Amplifier-type limiters can operate as grid limiters, saturation limiters, or cut-off limiters.

The grid limiter shapes that portion of the positive half of the signal which drives the tube into grid current. During the time of grid-current flow, most of the signal is developed across R_g, and the inversion in the tube produces a plate waveform with the negative peak removed.

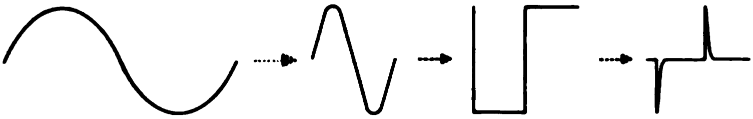
The overdriven amplifier limits the positive peaks of the input signal because of plate-current saturation, and the negative signals because of plate-current cut-off.



58. —Two limiters.

The overdriven amplifier and its circuit variations are used in fire control radars to develop square waves from sine waves. The square wave then may be reshaped more easily into a voltage pulse or trigger for use elsewhere in the radar system. The trigger, or pulse, retains a definite timing relationship to the sine wave that was used to produce it.

The examples given illustrate some of the variations of the overdriven amplifier. The function performed is the same, but you found other names used for the circuit—"Limiter," "Clipper," "Squaring Amplifier," and "Slicer." These are a few of the applications of this circuit to fire control radar equipments. Other names may be encountered, such as "Distortion Amplifier" or "Shaping Amplifier." Regardless of the names applied, the purpose of each circuit is the same—to develop a square-wave output using a sine-wave input.



59. —What can happen to a sine wave.

Notes

TOPIC 4: CATHODE FOLLOWERS

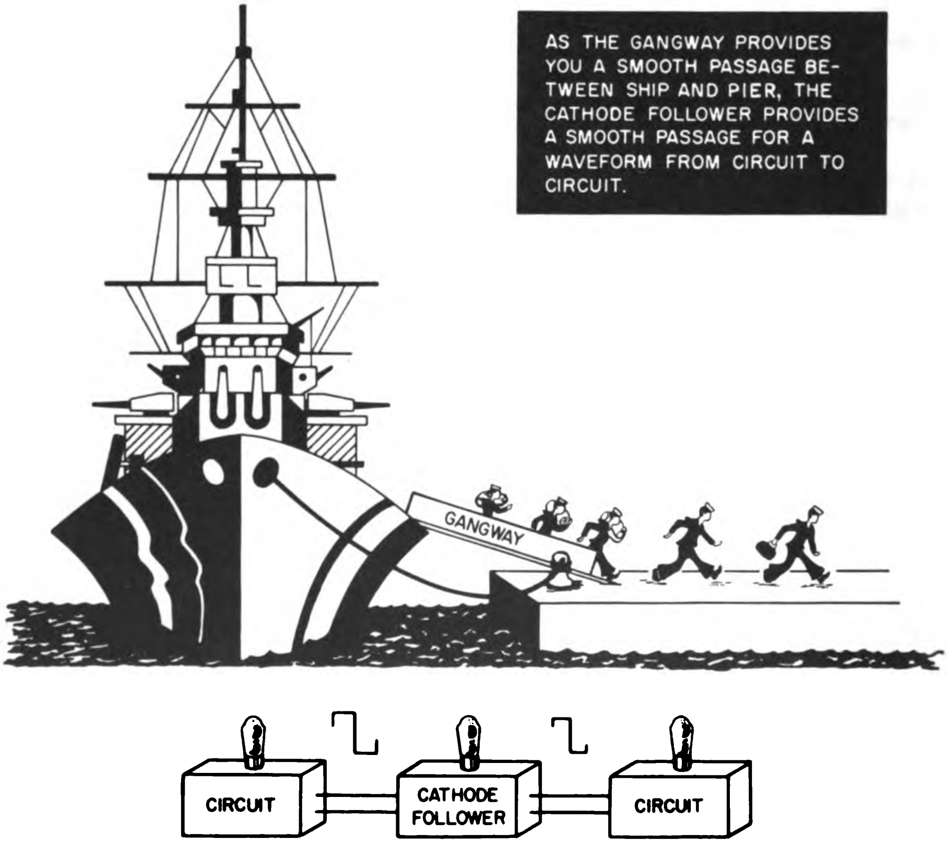
A Circuit Used in Many Places

By now, you are acquainted with the fact that there are three types of special circuits. Generating circuits create new waveforms; shaping circuits take waveforms that already exist and reshape them into more usable forms; and, finally, connecting circuits take waveforms from the output of one stage and feed them to the input of another stage.

Up to now, you have learned about a generating circuit (the Wien bridge audio oscillator) and a reshaping circuit (the overdriven amplifier). You are now going to learn about a circuit—the cathode follower—which can be used as both a connecting and reshaping circuit.

A cathode follower is a type of circuit which is found in almost every piece of electronic equipment used aboard Navy ships and is the most widely used circuit you have encountered since you studied amplifiers.

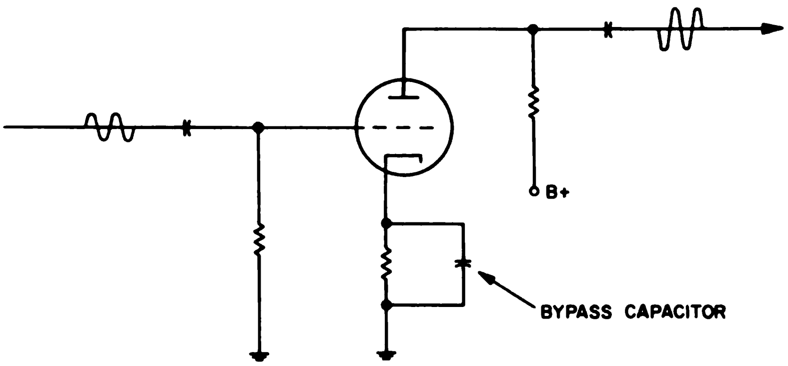
The reason that the cathode follower is used so much is that it can perform many different and useful functions, both as a connecting circuit and as a shaping circuit.



AS THE GANGWAY PROVIDES YOU A SMOOTH PASSAGE BETWEEN SHIP AND PIER, THE CATHODE FOLLOWER PROVIDES A SMOOTH PASSAGE FOR A WAVEFORM FROM CIRCUIT TO CIRCUIT.

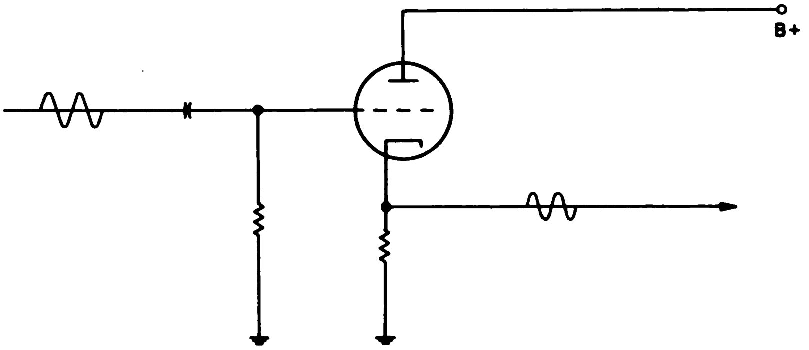
60. —Smooth passages.

What a Cathode Follower Is



61. —Conventional amplifier.

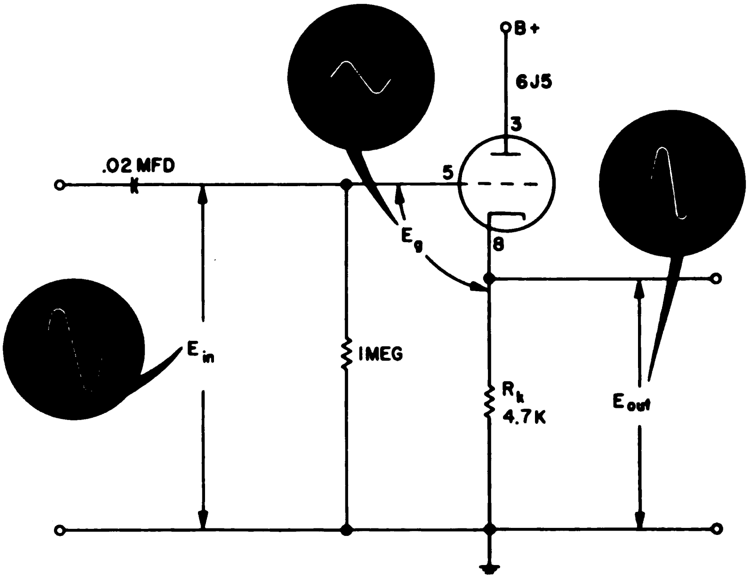
A cathode follower is a modification of the conventional amplifier. It has no plate-load resistor, or a bypassed one of very small value, and the cathode resistor is not bypassed. With a signal applied to its grid circuit, a voltage of the same polarity will be developed across the unbypassed cathode resistor. The cathode voltage "follows" the grid voltage and it is this fact that gives the cathode follower its name.



62. —Cathode follower.

How a Cathode Follower Works

With plate voltage applied to the tube, but no signal input, the grid is at ground potential. The cathode, due to the d-c plate current flowing through the tube, is at some voltage above ground because of the voltage developed across the 4.7K cathode resistor.



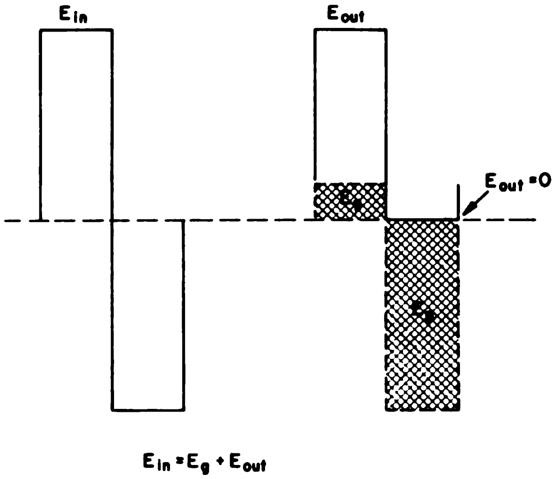
63. —How a cathode follower works.

Assume that a sine-wave signal voltage, E_{in}, is applied to the grid of the tube. As the grid becomes more positive, the plate current flowing through the tube increases and causes the cathode voltage, E_{out}, to increase. When the grid becomes more negative, the plate current decreases and the cathode voltage, E_{out}, decreases. Thus, the voltage across the cathode resistor is a duplicate of the input voltage as to waveform and phase.

E_{out} is always less than E_{in}. This is true, as there must be a change in E_g to produce a change in circuit current. If E_g remains constant, there will be no change in I_p. As E_{in} causes the grid voltage to change, I_p starts to change, thus changing E_{out}. As the I_p changes, it tries to produce a voltage that will re-establish the original E_g. This is never accomplished during the signal cycle. Then E_{in} will equal E_{out} plus E_g. For the above reasons, it can be seen that the gain of a cathode follower is always less than unity.

Thus, you see that when a sine wave is put into the cathode follower, the output is a sine wave of the same phase and frequency, but of smaller amplitude.

How a Cathode Follower Works (Continued)



64. —Limiting action of a cathode follower.

Now consider the circuit operation when the output of an overdriven amplifier is fed into the grid. The output of the overdriven amplifier is a square wave of rather large amplitude. Remember that when an input voltage of large amplitude was applied to the grid of the overdriven amplifier, limiting took place. A large positive peak drove the tube nearthe plate current saturation region, and a large negative peak caused the tube to cut off. Remember too that when the tube was cut off, the positive peak of the output voltage was limited to the value of B+.

When the output of the overdriven amplifier is fed through the .02-mfd coupling capacitor to the grid of the cathode follower, the negative peak is of a large enough amplitude to cause the negative peak of the grid-to-cathode voltage to go more negative than cut-off. Thus, on the negative input peak, the tube will be cut off, no current will flow in the cathode resistor, and the cathode will be at ground potential. The negative output peak is limited to ground potential.

With the plate current cut off and no output voltage developed, the grid voltage will equal the input voltage. Thus, the equation $E_{in} = E_{out} + E_g$ still applies since E_{out} is equal to zero.

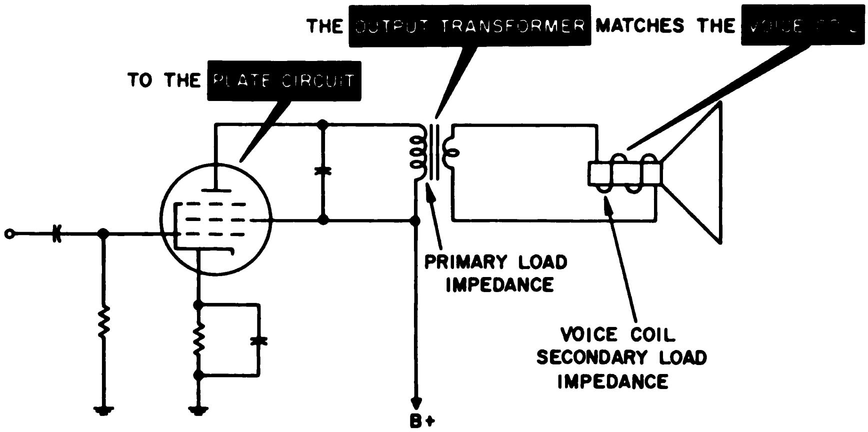
The above discussion demonstrates how a cathode follower, by limiting negative peaks, can be used as a limiter or shaping circuit.

CATHODE FOLLOWERS

How Cathode Followers Are Used

Cathode followers are useful in many circuits of fire control radars. They are useful as shaping, impedance-matching, and isolating circuits.

On the preceding page, you have seen how it may be used as a shaping circuit. Now you will learn how it can be used as an impedance-matching circuit. As you know from your previous studies of "Basic Electronics," considerable care was taken so that the audio output transformers had an output impedance to match the impedance of the speaker.

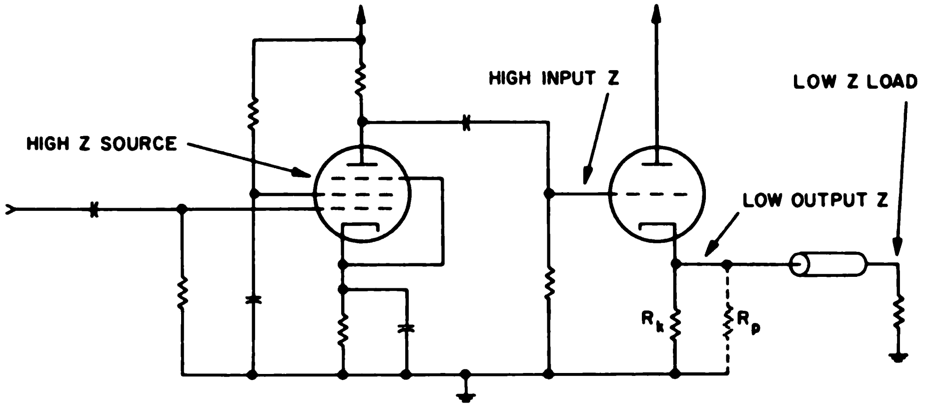

THE OUTPUT TRANSFORMER MATCHES THE VOICE COIL
TO THE PLATE CIRCUIT
PRIMARY LOAD IMPEDANCE
VOICE COIL SECONDARY LOAD IMPEDANCE
B+

65. —Use of cathode follower.

This was done so that enough power arrived at the speaker to produce undistorted sound. The same principles are applied to cathode followers when used as impedance-matching devices. In many cases, it is necessary to transmit signals through a length of cable. These signals may be comparatively small, or the characteristics of the cable may be such that the signal will be attenuated so much that it will not drive the next stage. To transfer the signal efficiently under these conditions is one of the primary purposes of cathode followers. Through proper design of the circuit and consideration of the tube type to be used, the relatively high impedance of the preceding stage can be matched to the low impedance of the cable. By matching the cathode follower to the characteristic impedance of the coaxial cable, it is possible to deliver the signal efficiently to the next stage.

You recall from your studies in "Basic Electronics" that the interelectrode capacitance existing between grid and cathode of a vacuum tube is relatively small. This phenomenon is utilized to advantage in cathode followers, as it represents a high impedance input. Contributing to the high input impedance is the unbypassed cathode resistor, which results in degenerative feedback. This allows a large positive signal to be applied to the stage without drawing grid current, thus preserving the high input impedance during the positive swing. These two conditions produce the high input impedance of the cathode follower which matches the high output impedance of the previous stage. The input impedance of a cathode follower is higher than that of the same tube used as a conventional amplifier.

Cathode Followers Used for Impedance Matching and as Buffers

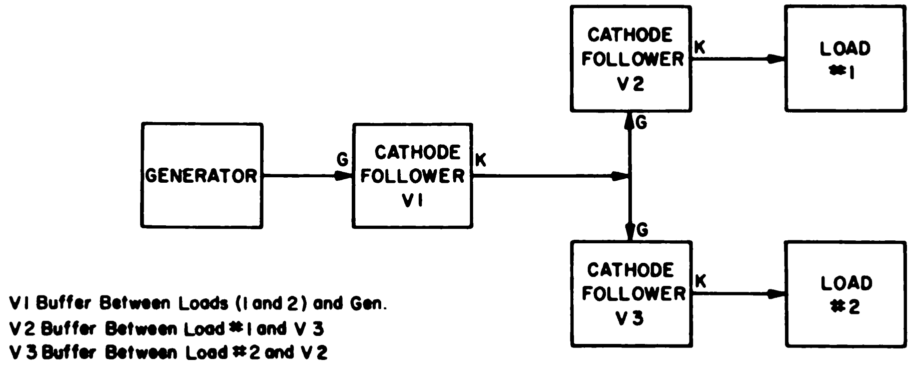


66. —The cathode follower as an impedance-matching circuit.

The low output impedance of the cathode follower is primarily determined by the ratio of its a-c plate resistance (r_p, as given in tube manuals) to its amplification factor (mu). A tube, used as a cathode follower, should have a relatively low r_p and a relative high mu. This ratio of r_p to mu produces an EFFECTIVE a-c plate resistance (R_p), which is low.

The output impedance of the cathode follower is determined by the parallel combination of the R_p and the R_k. Since both are in parallel and the R_p is usually in the region of 100 to 500 ohms, it is the more critical factor in establishing the output impedance. In some cases a dual triode is used with its two sections paralleled in order to reduce the output impedance. In practice, you will find that the cathode resistor may vary from several hundred to several thousand ohms with only a slight effect on the output impedance.

Another application of the cathode follower is its use as a buffer. It may be placed between a generating circuit, such as an oscillator or a multivibrator, and the next stage. This will prevent interaction between the two stages. It eliminates the undesirable effect of any stray capacitance between the generating circuit and its load that would produce instability in the generating circuit.


CATHODE FOLLOWER V2
K
LOAD #1
G
GENERATOR
G
CATHODE FOLLOWER V1
K
G
CATHODE FOLLOWER V3
K
LOAD #2
V1 Buffer Between Loads (1 and 2) and Gen.
V2 Buffer Between Load #1 and V 3
V 3 Buffer Between Load #2 and V 2

67. —The cathode follower as a buffer.

CATHODE FOLLOWERS

Experiment—Test Setup

In this experiment, you will observe the cathode follower in operation. You will feed the square wave from the high impedance output of the overdriven amplifier to the grid of the cathode follower, and note how the cathode follower delivers the square wave, without distortion, across its low impedance output with only a slight drop in gain.

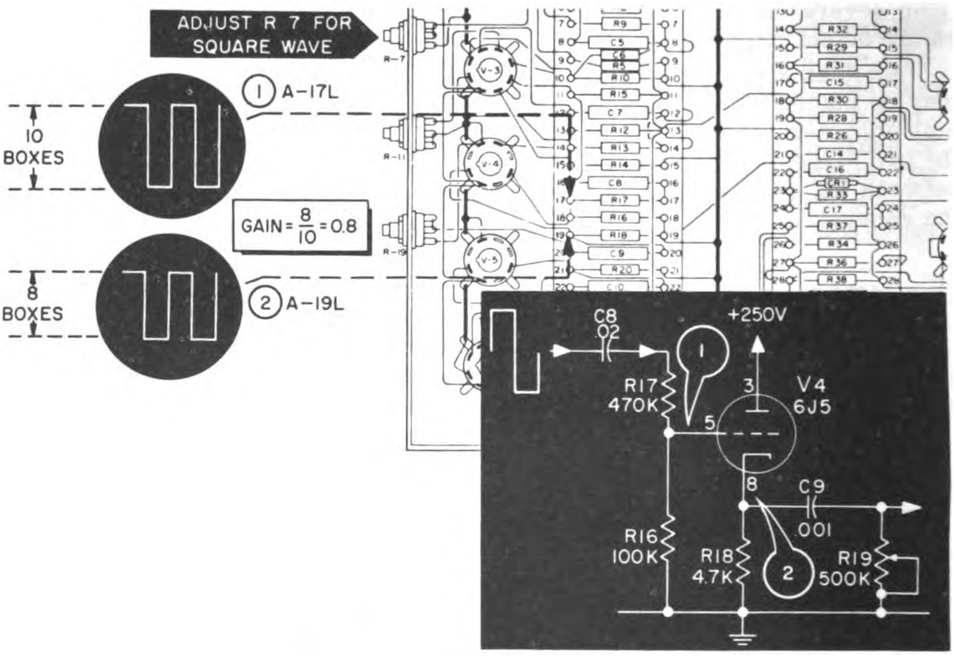
You will need a 'scope, a multimeter, a 6J5 tube, a .005- and a 0.1-mfd, 600-volt tubular paper capacitor.

The test setup for this experiment is shown below. The 'scope external sync lead is connected to the cathode of V2B (A-6L), and the 'scope is switched to external sync. Potentiometers R11, R4 and R19 are at their maximum settings (completely clockwise) and R7 is at its minimum setting. The 'scope vertical input test probe is ready to be attached to the check points in the cathode follower circuit.

Experiment—Checking Phase and Gain

Attach the 'scope probe to point 1, the grid of V4 (A-17L), and apply power to the chassis and 'scope. With R11 and R4 at maximum, increase R7 until you note a good square wave. Set the 'scope vertical gain control so that the peak-to-peak amplitude is 10 boxes and note the phase of the signal. Next, place the 'scope probe on point 2, the cathode (A-19L) of the cathode follower. Note that the waveform is identical to the input, both in phase and form.

Note also that the peak-to-peak amplitude is about 8 boxes. This establishes the gain of the cathode follower at about 0.8 (8/10), or less than one.



68. —Cathode follower—test setup.

CATHODE FOLLOWERS

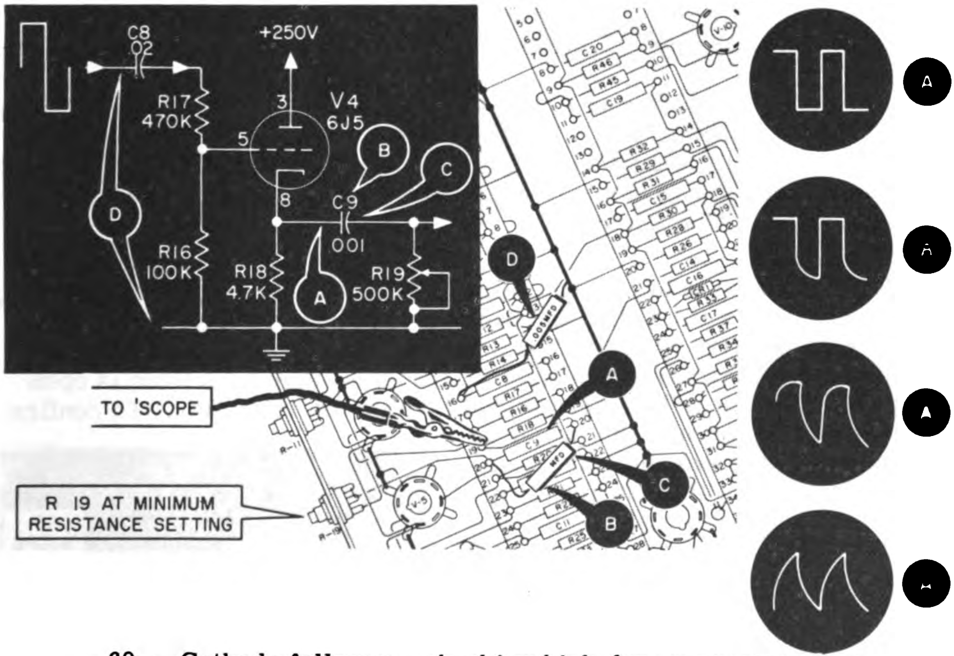
Experiment—Checking High-Frequency Response

The cathode follower has excellent high-frequency response, because of its low output impedance. Shunting effects of stray and load capacities are pronounced only at high frequencies. This can be shown by noting what values of shunt capacity attenuate the square wave.

Slowly decrease R19 from maximum while observing square wave with 'scope probe at cathode (A-19L). When R19 is at zero, placing C9 directly across the cathode, the waveform is hardly affected. The steep sloping sides of the square wave remain. This proves that the shunt impedance of C9 is much greater than the low output impedance of the cathode follower.

Now, place a .005-mfd capacitor in shunt with C9. Repeat the experiment. You should just be able to observe an effect when R19 is near its zero setting. There should be a slight rounding at the base of the waveform.

Now, replace the .005-mfd capacitor with a 0.1-mfd capacitor and repeat the experiment. Since the capacitor charges through the tube faster than it discharges through the cathode resistor, the shunting effects are more pronounced. This produces the unequal curvature of the waveform.



69. —Cathode follower—checking high-frequency response.

Now, to show that a plate-loaded amplifier is affected much more by shunt capacitance than a cathode follower, connect a .005-mfd capacitor across the output of the overdriven amplifier (A-16L to ground). Observe waveform at A-19L and note greatly increased curvature.

The rounding of the steep sides of the square wave was the result of poor high-frequency response, because of shunt capacitance. A small shunt capacity had a more pronounced effect on the output of the amplifier than a larger shunt capacity had on the output of the cathode follower. This proves the good high-frequency response of the cathode follower even with considerable shunt capacity across its load.

CATHODE FOLLOWERS

Experiment—Trouble Shooting

The procedure used to trouble shoot the cathode follower is exactly the same as that used to trouble shoot any amplifier stage. Again briefly repeating this procedure, it involves isolating the trouble to a defective stage (usually by signal tracing), and then isolating the defect to a particular component in that stage by voltage and resistance measurements.

You will first insert a specific defect, as stated below, into your circuit and then you will follow the outlined procedure for tracking down the trouble. As you follow the steps, try to understand the logic behind them; namely, why step 3 is where it is and not in some other place. If you can understand this reasoning, you will be able to apply similar reasoning when you are confronted with a real servicing problem. You will thus track down the trouble methodically and easily, rather than haphazardly and tediously.

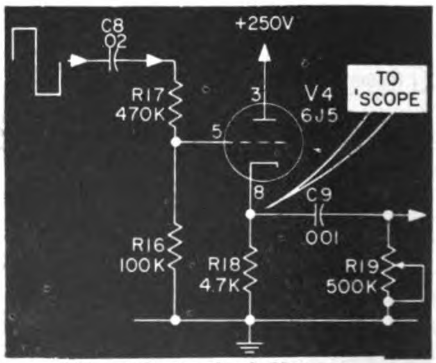
Trouble No. 1—See the next sheet for the illustration relating to the following steps. Simulate an open cathode resistor by unsoldering R18 from A-19R.

Now, proceed to isolate the trouble to the defective stage. Connect the 'scope probe to A-19L and observe that the waveform appears distorted. Next, check the input to the cathode follower at A-18L and observe that the waveform is normal. The trouble has been localized to the cathode follower stage. Since there is an output, although distorted, you can assume that the tube is probably good. This also indicates that filament and B+ voltages are available.

Your next step is to check voltages. Set the voltmeter to a high scale, and connect it between A-19L and ground. You observe that the meter reads a high positive voltage. You know that this is not the normal cathode potential. Therefore, you conclude that the cathode resistor is open and the tube circuit is being completed through the voltmeter. To confirm your conclusion, secure the power to the chassis and check the cathode resistance to ground. The reading is near infinity. (With the 'scope probe removed, the reading would be infinity.) This proves that R18 is open.

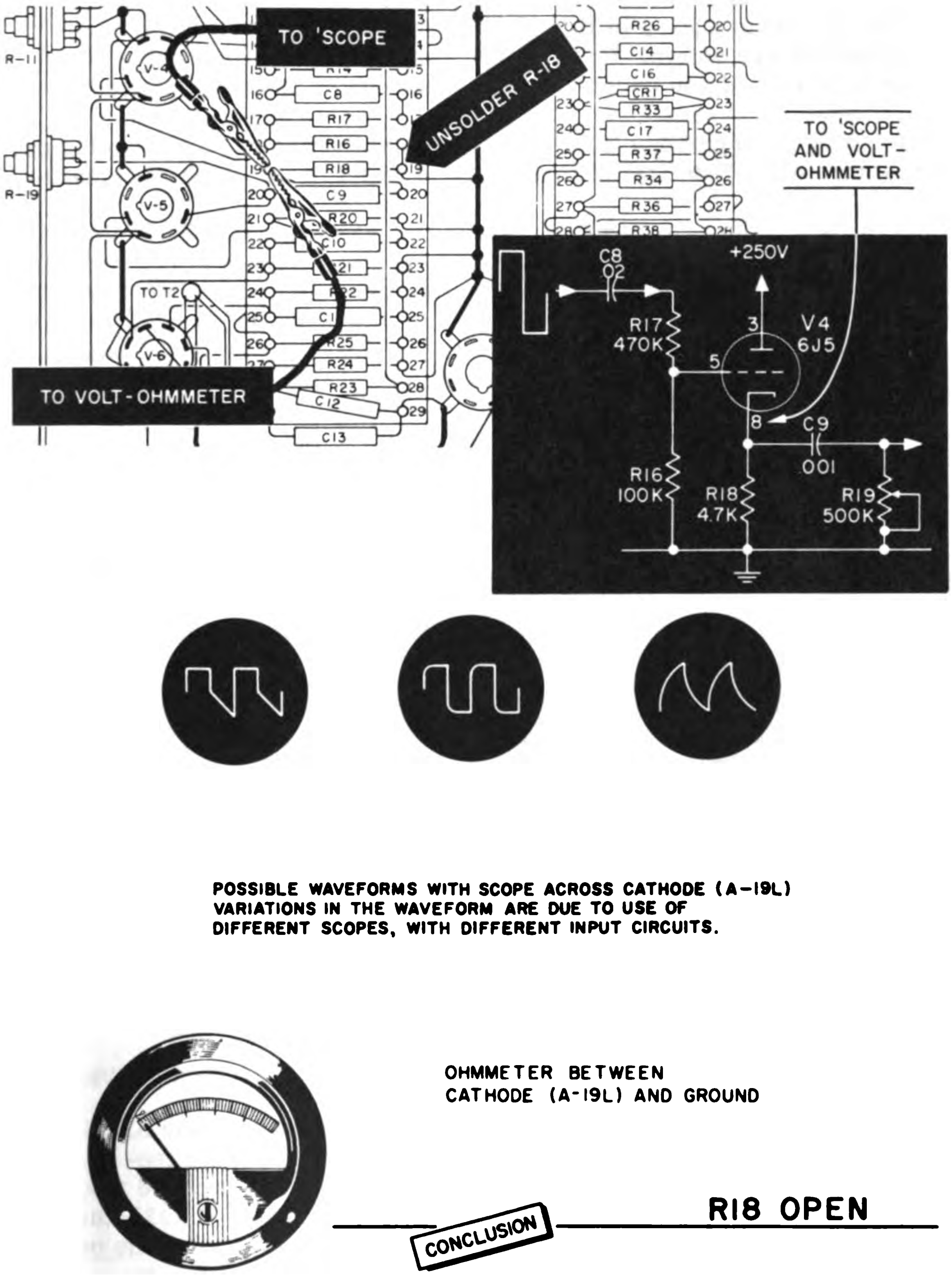
Resolder R18 to A-19R.

Note that the only reason a waveform was observed at A-19L was because of the input resistance of the 'scope shunting the open cathode resistor.



70. —Cathode follower—trouble shooting (I).

Experiment—Trouble Shooting (Continued)



POSSIBLE WAVEFORMS WITH SCOPE ACROSS CATHODE (A-19L)
VARIATIONS IN THE WAVEFORM ARE DUE TO USE OF
DIFFERENT SCOPES, WITH DIFFERENT INPUT CIRCUITS.

OHMMETER BETWEEN
CATHODE (A-19L) AND GROUND

CONCLUSION R18 OPEN

71. —Cathode follower—trouble shooting (II).

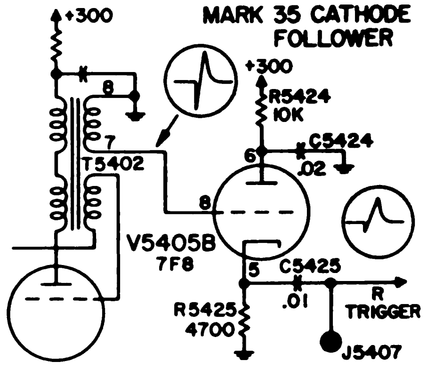
You will now insert troubles into your partner's chassis and he in yours—anywhere in the circuits you have already tested. Be sure to get the instructor's ok before inserting the trouble.

Applications—Cathode Followers

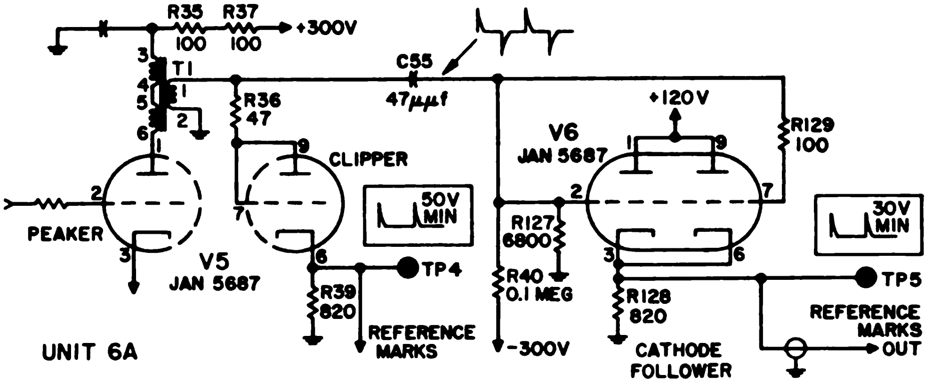
Shown below and on the following pages are some representative cathode follower circuits used in fire control radars. A very limited number of applications are shown. However, you should have little trouble with cathode followers if you understand the functions of those presented here.

Below are two cathode follower circuits which are used as shaping or clipping circuits. The first of these will be found in the Mark 35 Radar.

Note that since a positive- and negative-going waveform is induced in the secondary winding of transformer T5402, the negative swing of terminal 7 is negative in respect to ground (Term. 8). Since the cathode of V5405B cannot be driven below ground, the output of the cathode follower is clipped at ground potential. However, the positive swing of the grid (Term. 7 of T5402) is passed by the cathode follower. This R Trigger is used to trigger a multivibrator to produce sweep voltages for a cathode-ray tube.

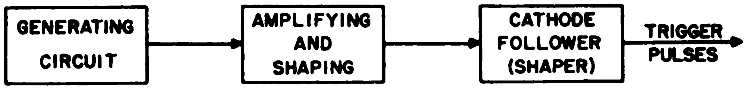


72. —Mark 35 cathode follower as a clipping circuit.



73. —AN/SPG-48 cathode followers as a shaping and impedance-matching circuit.

A similar application of the cathode follower is found in the AN/SPG-48. The output of T1, across the 1-2 winding, consists of positive- and negative-going pulses. Since grids 2 and 7 of cathode follower V6 are below cut-off potential, due to the voltage divider composed of R127 and R40, the negative swing will have no effect on the output of V6. The output will be the positive pulses. These pulses are the reference marks and are fed to the video system. The two sections of V6 are connected in parallel to secure a lower output impedance. This cathode follower functions as both a shaping circuit and as an impedance-matching circuit.

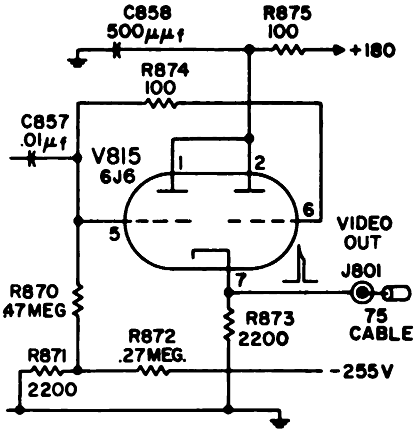


74. —Generation of trigger pulses.

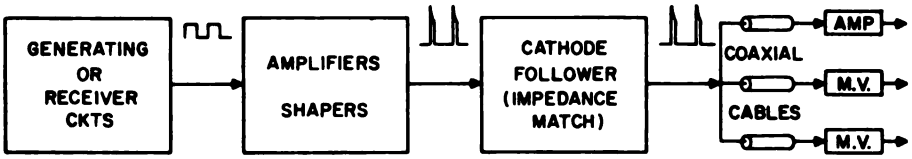
Applications—Cathode Followers (Continued)

On this page are shown two applications of cathode followers used as impedance-matching devices for coaxial cables. The first is a circuit that will be encountered in the Mark 35 Radar.

This circuit is used to match the high output impedance of the preceding amplifier stage to the low impedance of the coaxial cable. It is located in the second stage following the second detector in the Receiver circuits of the radar. To insure that weak video signals will drive the video circuits requires the use of proper impedance matching. The positive output of the previous stage is coupled to V815, with both halves connected in parallel to reduce the R_p of the stage. V815 feeds the video to jack J801, and through this to the 75-ohm cable which carries the video signals to the indicators and the range error detector.

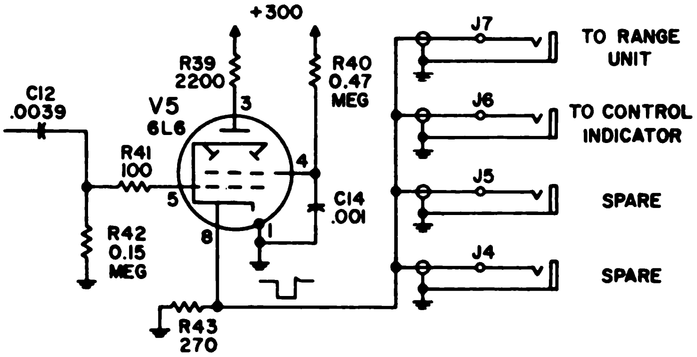


75. — Mark 35 cathode follower as an impedance-matching circuit.



76. — Block diagram of Mark 35 Radar.

Below is a cathode follower used in the Mark 34 Radar.

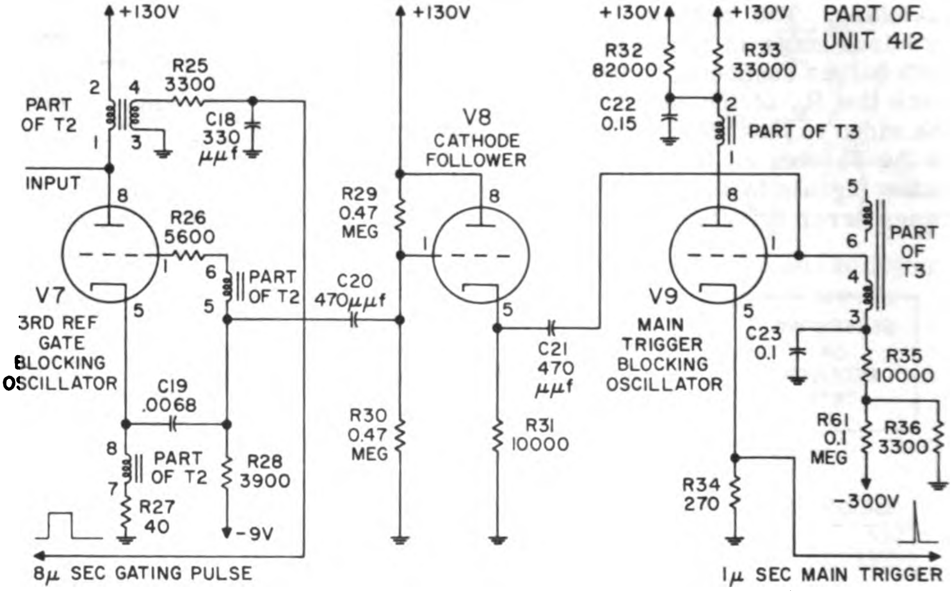


77. — Mark 34 cathode follower as an impedance-matching circuit.

Its function here is to match impedance of the coaxial cables which connect the output to other units of the equipment. The signal in this case is the pulse repetition frequency of the radar and is used to synchronize other circuits in the system. (Note the exception in the circuit of V5 to that of the conventional cathode follower. R39 in the plate circuit is unbypassed. The function of this plate resistor is to limit the plate current in V5.)

Applications—Cathode Followers (Continued)

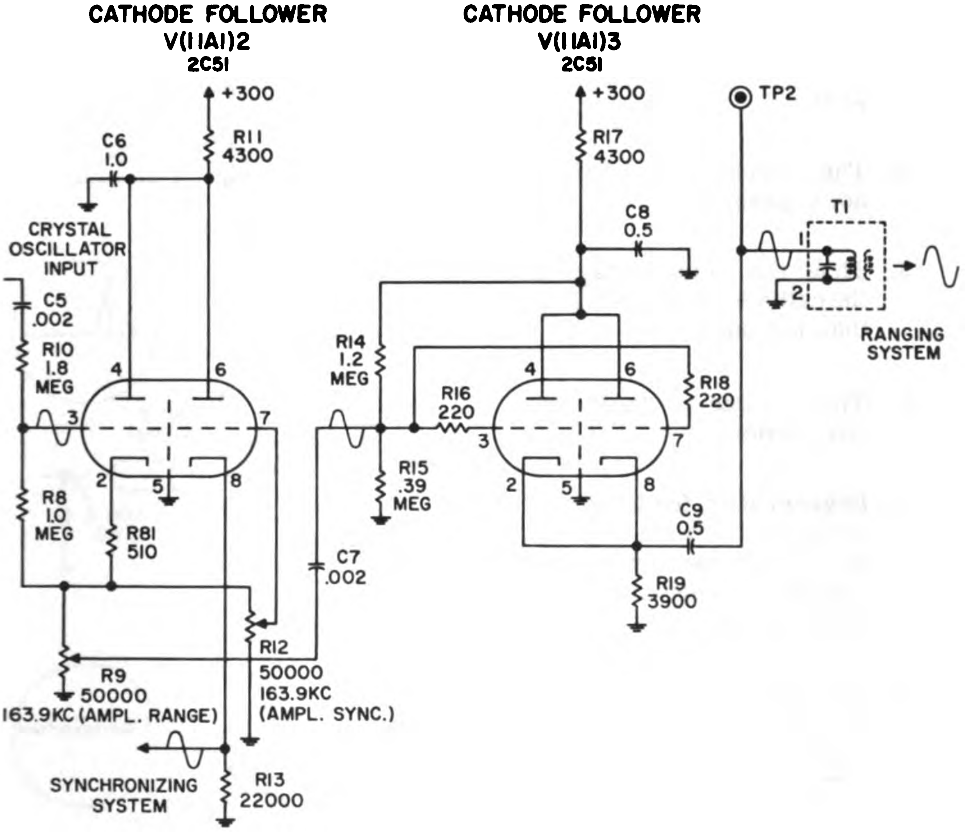
In Radar Set AN/SPG-50, a cathode follower is used as a buffer between two blocking oscillators. The outputs of the two blocking oscillators, V7 and V9, are of different duration. The output of V9 is a 1-microsecond pulse, and it is used to start the generation of sweeps and a ranging pulse. The output of V7 is an 8-microsecond pulse. It initiates the triggering of the magnetron, which must occur several microseconds later. Any interaction between these pulses would upset the precision timing of the system. Cathode follower, V8, prevents interaction and effectively isolates these two pulses.



78. — AN/SPG-50 cathode follower as a buffer.

Applications—Cathode Followers (Continued)

This circuit from the Mark 25 Radar is also used for isolation. Section 2-3-4 of V2 effectively isolates the Synchronizing System (output at R13), and the Ranging System from the generating source (crystal oscillator). Section 6-7-8 of V2 isolates the Synchronizing System from the Ranging System. This is necessary, because of considerable phase-shifting occurring in the Ranging System which could seriously affect the stability of the Radar Transmitter and Indicators. V3 aids in this isolation and provides impedance matching for the input to the Ranging System (T1).



79. — Mark 25 cathode followers as an isolator and impedance matcher.

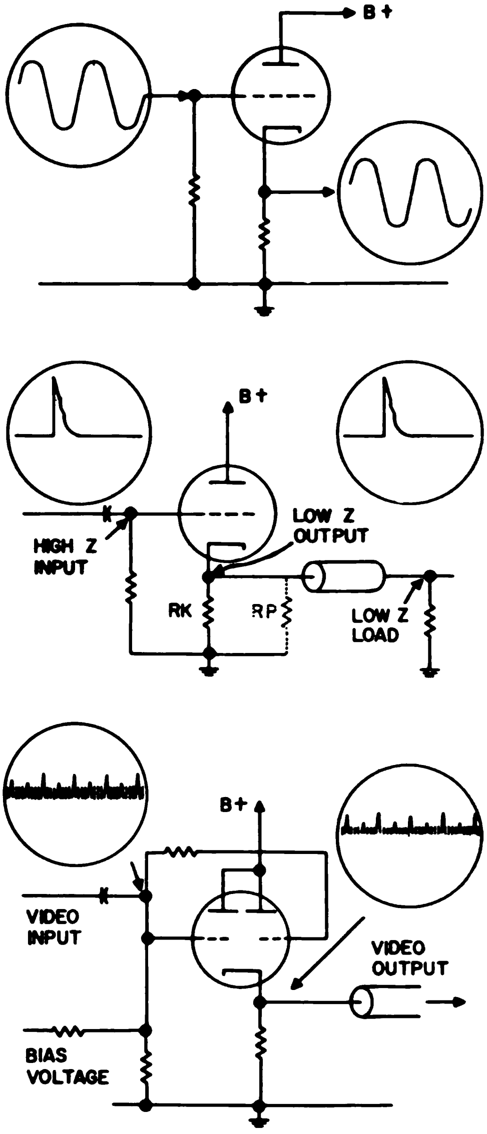
CATHODE FOLLOWERS

Review

In this topic, you acquainted yourself with the cathode follower, a circuit which is the most widely used of any circuit in radar. Its most common application is as an impedance-matching device, matching a high output impedance of a circuit with the low input impedance of another circuit or a coaxial cable. Other uses are as buffers (isolation) and shaping.

Some of the facts that you have learned in this topic are:

1. The plate is connected to B+ or, if a plate-load resistor is used, it is decoupled.
2. The cathode resistor is not bypassed.
3. Thus, the output voltage of the cathode follower is less than the input.
4. This is due to degenerative feedback.
5. Degenerative feedback and the interelectrode capacitance between grid and cathode produce the high input impedance.
6. The EFFECTIVE a-c plate resistance (R_p) is usually in the range of 100 to 500 ohms and is the controlling factor in producing its low output impedance.
7. The cathode follower has good high-frequency response which is desirable in video circuits.



80. — Review diagram.

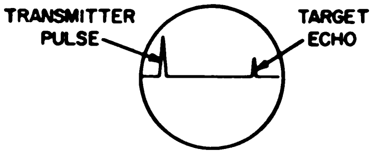
Notes

TOPIC 5: DIFFERENTIATING CIRCUITS

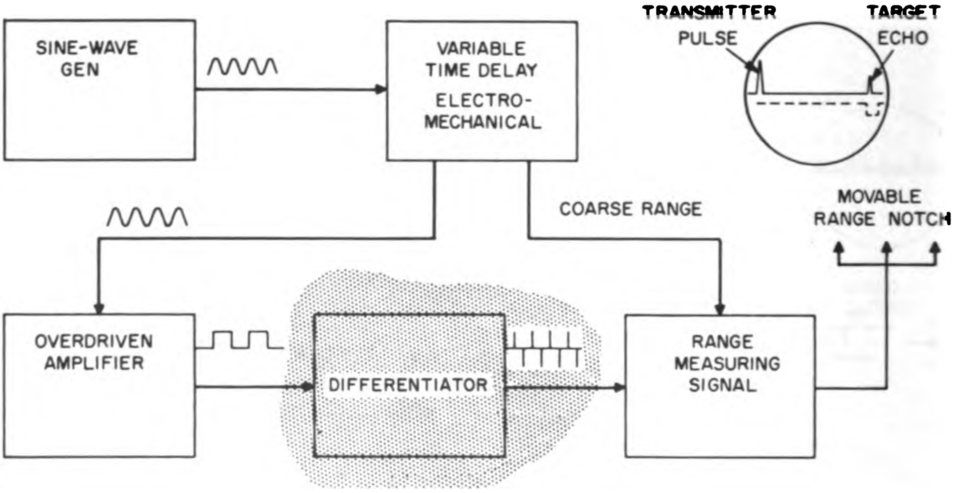
General Purpose in Radar

Sharp pulses, or triggers, are essential in the timing circuits of fire control radar equipments. These pulses may be either positive or negative. The positive pulses are used to raise the grid voltage of tubes that are cut off and cause them to conduct. The negative pulses are used to cause conducting tubes to be cut off. These pulses are used to initiate circuit actions to develop sweeps, to provide time delays, and to permit electronic switching. These sharp pulses, or triggers, are usually the outputs of differentiating circuits.

The differentiating circuit produces an output voltage that is proportional to the rate of the change of the input voltage. The steeper the sides of the input signal, the sharper is the output of the differentiator. When the change is in a positive direction, the output of the differentiating circuit is in a positive direction and when the change is in a negative direction, the output voltage is negative. If a square-wave voltage is applied to the circuit, the output of the differentiating circuit will consist of positive and negative voltage spikes that coincide with the leading and trailing edges of the input.



WHAT IS THE RANGE ?



81. — The differentiator.

Differentiating circuits perform an important function in obtaining the accurate range measurements of all fire control radar equipments.

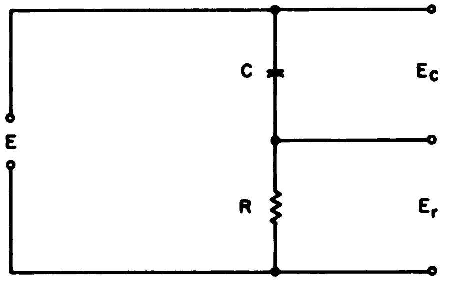
DIFFERENTIATING CIRCUITS

Introduction to R-C and L/R Circuits

This topic is devoted to the characteristics of resistors and capacitors connected in series, the variations in voltage produced across each of them during a given time period, and their uses in radar circuits. These combinations are referred to as R-C circuits and, as previously stated, are utilized in many of the circuits of fire control radars.

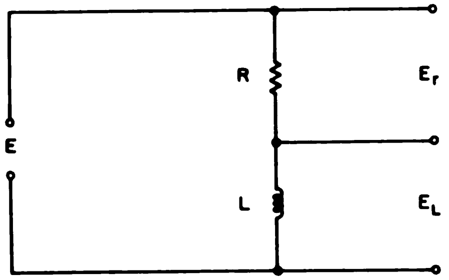
As you already know, a voltage drop will appear across a resistor only when a current flows through it.

You also recall that an uncharged capacitor is one in which both plates contain an equal number of free electrons. The difference in the number of these electrons is a measure of the charge on the capacitor. Increasing the difference in the number of electrons is accomplished by applying an EMF. The charge on the capacitor will increase until it reaches the same value as the applied EMF. Unless a discharge path is provided, a perfect capacitor would keep its charge indefinitely. However, a practical capacitor has some leakage through the dielectric so that a charge will leak off very gradually.



82.— R-C circuit.

This topic will also deal with the characteristics of resistors and coils connected in the same manner as in R-C circuits. These circuits are very similar in all respects. When resistors and coils are connected in this manner, they are referred to as L/R circuits or peakers.



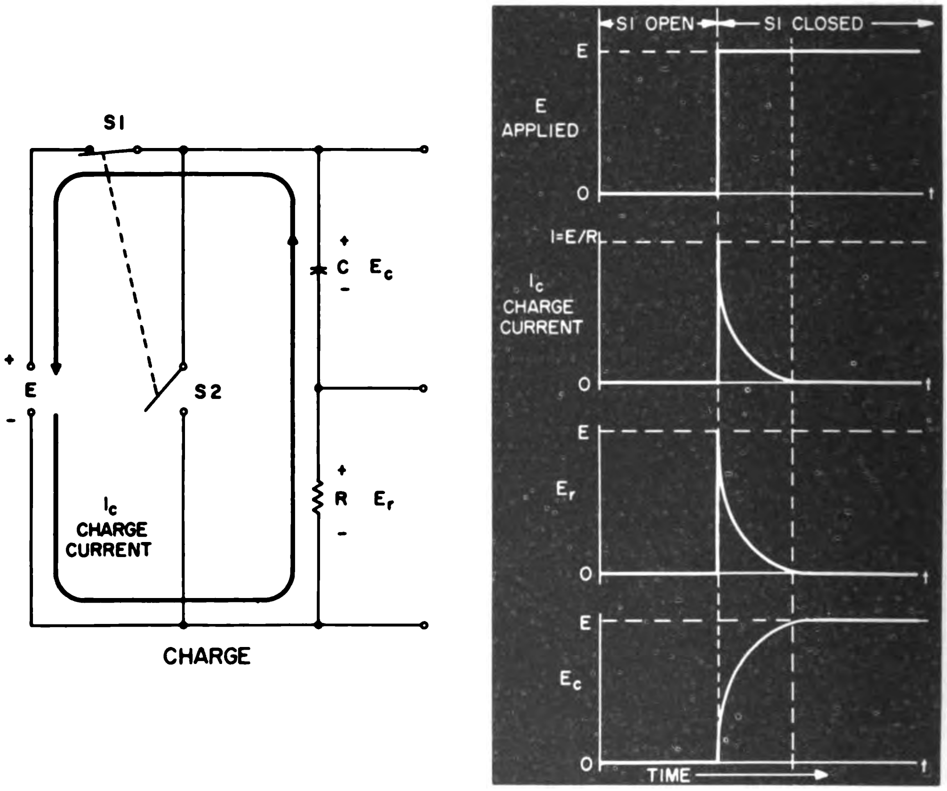
83.— L/R circuit.

DIFFERENTIATING CIRCUITS

R-C Charging

Shown below is an R-C circuit (voltage divider) connected to a d-c supply and two switches. If S1 is closed, electrons are attracted from the upper plate of the capacitor. This electron flow is the current, I_C, which charges the capacitor. At the instant current begins to flow, there is no voltage on the capacitor; thus, voltage E across the divider must appear as the voltage drop across the resistor. The initial current then must equal E/R. The chart below shows that at the instant the switch is closed, all the applied voltage, E, appears across R and the voltage across C is zero.

After a small interval of time, the circuit current soon charges the capacitor a small amount. Since the capacitor voltage is proportional to the charge on it, a small voltage, E_C, appears across the capacitor. At this time, the applied voltage, E, minus the small voltage, E_C, will equal the resistor voltage, E_r, which is developed by the I_C flowing through it.



84. — R-C charging.

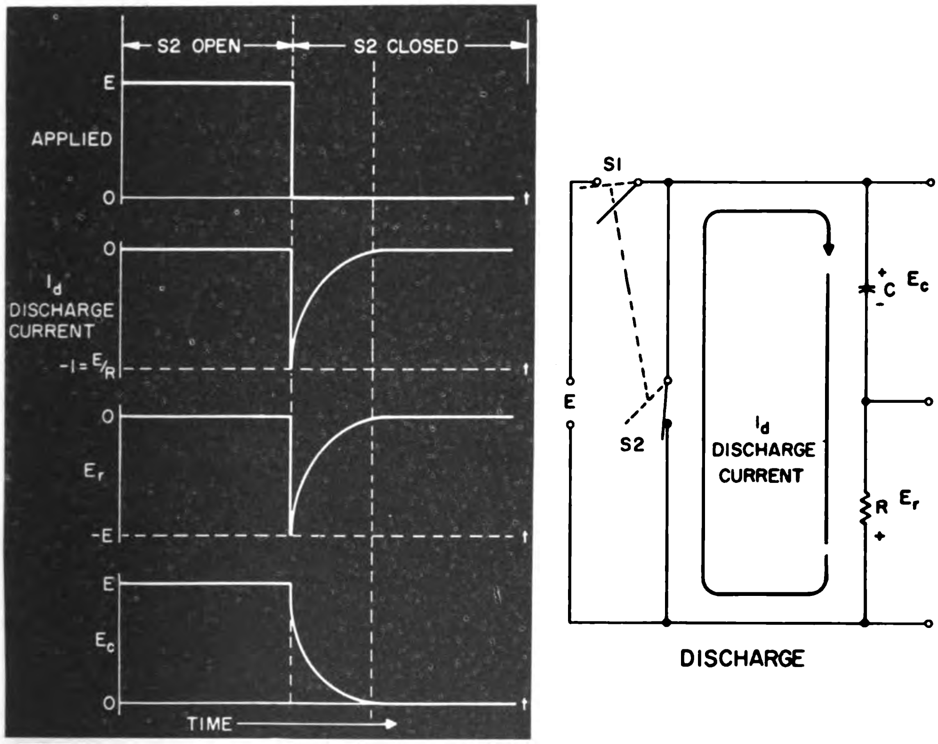
This process continues, with E_C becoming larger and E_r becoming smaller, until a time is reached when E_C will equal the applied E. The capacitor never becomes fully charged and a small voltage will appear across the resistor. However, if S1 is closed long enough, for all practical purposes a condition of full charge is considered to be attained.

R-C Discharging

Below is shown the discharging cycle of the same R-C circuit. Take time and compare the waveforms of the charging cycle with those of the discharging cycle.

Assuming that C is a perfect capacitor and that it is charged to the applied voltage, it would remain so even when S1 were opened, and its charge would equal E. At this time there is a difference in the number of free electrons on the plates of the capacitor.

Now, with S1 open and S2 closed, we provide a discharge path for the capacitor and a discharge current, I_d, flows to bring the capacitor to balance. Since the capacitor is now the source, the voltage developed across the resistor is of opposite polarity to that on the charging cycle. The magnitude of this voltage will be the same and will vary just as it did while the capacitor was charging.



85. — R-C discharging.

Note that on the charging cycle E applied equals $E_c + E_r$ and on the discharge cycle E applied equals 0 at the instant the switch is closed. Then, since the capacitor is returning to balance, $E_c + E_r$ equals 0.

DIFFERENTIATING CIRCUITS

R-C Time Constant

The time required to charge a capacitor to 63 percent or to discharge it to 37 percent of its final voltage is known as the time constant of the circuit. The value of this time constant in seconds is equal to the product of the circuit resistance in ohms and capacity in farads. R-C is the symbol for this time constant.

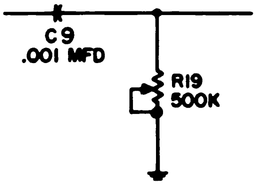
Listed below are some useful relations often used in calculating time constants.

R (in ohms) x C (in farads) = t (in seconds)
R (in megohms) x C (in microfarads) = t (in seconds)
R (in ohms) x C (in microfarads) = t (in microseconds)
R (in megohms) x C (in micromicrofarads) = t (in microseconds)

The last two are those most frequently encountered in radar.

Your comprehension of R-C time and its calculation will make your study of fire control radar circuits much easier and more interesting.

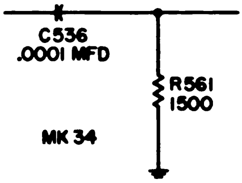
Some examples of R-C time calculations are given below.



R (in ohms)x C (in microfarads) = t (in μ sec)

$t = 500{,}000 \times .001 = 500\ \mu$ sec

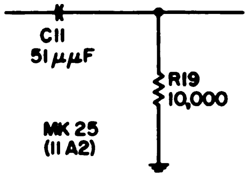
or $t = (5 \times 10^5)\ 10^{-3} = 5 \times 10^2 = 500\ \mu$ sec



R (in ohms)x C (in microfarads) = t (in μ sec)

$t = 1500 \times .0001 = .15\ \mu$ sec

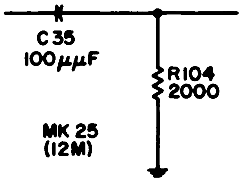
or $t = (15 \times 10^2)\ 10^{-4} = 15 \times 10^{-2} = .15\ \mu$ sec



R (in megohms) x C (in micromicrofarads) = t (in μ sec)

$t = .01 \times 51 = .51\ \mu$ sec

or $t = (10^{-2})\ (51) = 51 \times 10^{-2} = .51\ \mu$ sec



R (in megohms) x C (in micromicrofarads) = t (in μ sec)

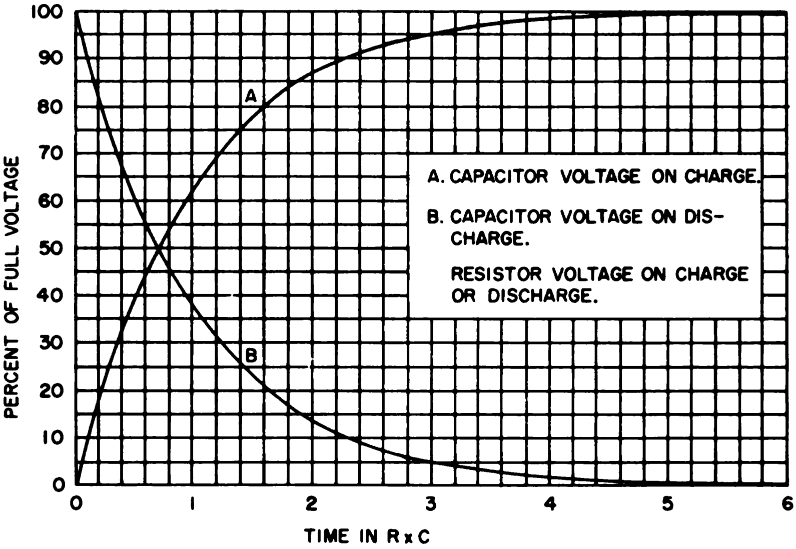
$t = .002 \times 100 = .2\ \mu$ sec

or $t = (2 \times 10^{-3})\ (10^2) = 2 \times 10^{-1} = .2\ \mu$ sec

86. — R-C time calculations.

R-C Time Constant (Continued)

Since the impressed voltage and values of R and C usually will be known, a universal time-constant chart can be used. This is an accurate graph of the voltage rise or fall across the capacitor and across the resistor in a series R-C circuit. The time scale is graduated in terms of the R-C product, so that the curves may be used for any values of R and C. The voltage scale is graduated in terms of percent of full voltage, so that the curves may be used for any voltage. If the time constant and the initial or final voltage for the circuit in question are known, the voltages across various parts of the circuit can be obtained from the curves for any time after the switch is closed, either on charge or discharge.



87. — R-C time-constant curve.

It is seen from these curves that in 1 R-C time, the charge reaches 63 percent of full value. Also in 2.3 R-C time, 90 percent of the full change in voltage is reached. In the next 2.3 R-C time, or in a total of 4.6 R-C time, 90 percent of the remaining 10 percent change or 99 percent of the total change is reached. A third 2.3 R-C time interval later, or after a total 6.9 R-C time, 99.9 percent of the change has occurred. Theoretically, the capacitor never reaches full charge, but after 5 R-C time, more than 99 percent of the change in voltage has occurred, and for most practical purposes this is sufficiently close to full charge to be considered as such.

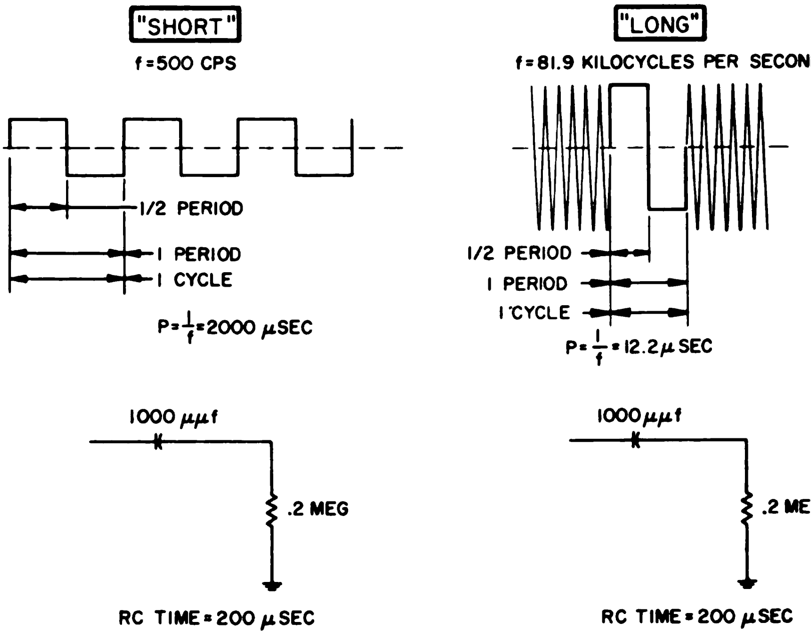
Note that during charge when the capacitor voltage reaches 63 percent of full charge on curve A, the resistor voltage will have dropped to 37 percent on curve B. Then, for any R-C time, the sum of the percentages of voltage on the capacitor and of voltage across the resistor will equal 100 percent of the applied voltage.

R-C Time Constant (Continued)

The transient effects of d-c circuits have been considered up to this point. If a square-wave voltage is substituted for the d-c input voltage in the circuits already discussed, the same principles may be applied in the analysis of transient behavior.

In R-C circuits to which square waves are applied, it is necessary to consider the R-C time relative to the time duration of the square-wave voltage. Such terms as "long," "medium," and "short" time constants provide a means by which the R-C time can be compared to the period time of the applied square wave.

To compare R-C time with the time duration of the square wave, you should know how to compute period time. You already know how to compute R-C time. To compute period time, you simply divide the frequency in cycles per second into one second. This gives you the duration of one cycle.

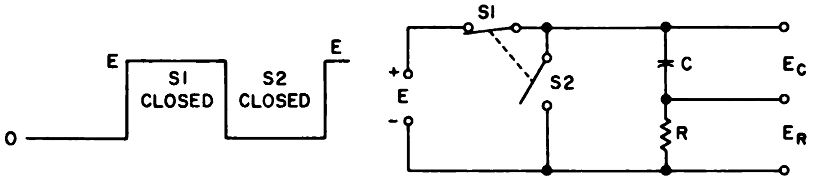


88. — Period time computation.

In practice, if the time of an R-C circuit is ten or more times greater than period time, the R-C is considered to be **LONG**. An R-C time constant of one-tenth (or less) than the period time is considered to be **SHORT**. In an R-C circuit, if the voltage across the resistor is used as the output, it is referred to as a **DIFFERENTIATOR** and, if the voltage across the capacitor is the output, it is referred to as an **INTEGRATOR**.

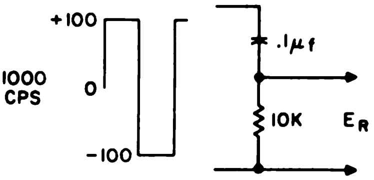
R-C Time Constant (Continued)

In this topic, you have been opening and closing switches to charge and discharge R-C circuits. This process is directly related to the generation of a square wave. Note in the square wave shown below that when S1 is closed, the voltage rises from zero to a value E. Likewise, when S1 is opened and S2 is closed, the voltage drops from E to zero.

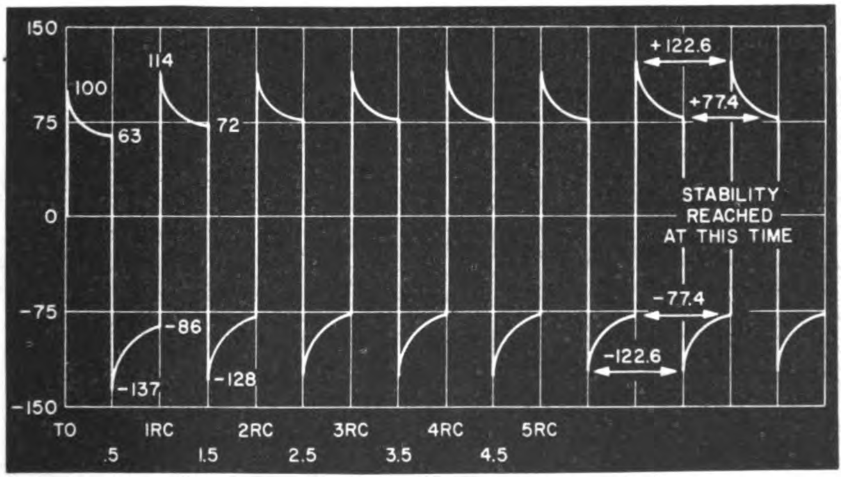


89. — Effect of switch action in an R-C circuit.

Shown below is the waveform produced across a resistor in an R-C circuit which has a square-wave input of +100 to -100 volts. The R-C time is 1000 microseconds and the frequency of the square wave is 1000 cycles per second. The waveform indicates the action produced in a circuit at the instant it is energized. Note that it requires 5 R-C time for the circuit to reach stabilization; that is, where the positive and negative peaks are of equal amplitude relative to the reference (zero in this case). When considering radar circuits, it is usually assumed that the circuit has been operating long enough for it to have reached an equilibrium.



90. — R-C circuit waveform at 0 R-C time.

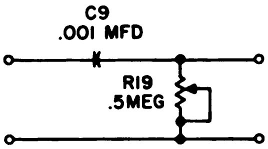


91. — R-C circuit waveforms from energizing to stabilization.

DIFFERENTIATING CIRCUITS

Seeing How the Differentiating Circuit Works

In the experiment which you will perform later in this topic, you will examine the output of the differentiating circuit for various values of resistance. Changing the resistance value is accomplished by varying the setting of the potentiometer shaft. The input to your circuit will be the output from the cathode follower circuit you studied in the previous experiment.



92. — Differentiating circuit.

In the preliminary discussion of the differentiating circuit, you learned that the output of a differentiating circuit consisted of the voltage developed across the resistor during the charge and discharge of the capacitor. You also learned that the capacitor is completely charged, for our purpose, in a time equal to 5 R-C time and completely discharges in the same time. Thus, you can see that the value of the product of the circuit resistance and the circuit capacitance governs the rate of the capacitor charge and discharge.

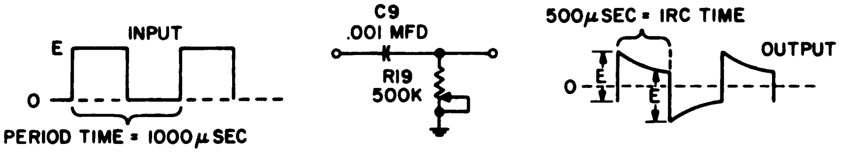
With the full .5-meg resistance in the circuit, the R-C time constant is 500 microseconds.

$$t \text{ (in microseconds)} = R \text{ (in ohms)} \times C \text{ (in microfarads)}$$

$$t = 500{,}000 \times .001 = 500 \text{ microseconds}$$

$$\text{or } t = (5 \times 10^5)\, 10^{-3} = 5 \times 10^2 = 500 \text{ microseconds}$$

Suppose a 1000-cycle symmetrical square wave is fed into the circuit. The period of this square wave would be 1000 microseconds. Since the square wave is symmetrical, the duration of the positive and the negative portions of the waveform would each be 500 microseconds. The capacitor would charge to a voltage equal to 63 percent of the input voltage during one-half cycle (one R-C time constant) and this would leave the remaining 37 percent of the input voltage across the resistor. The output of this differentiator resembles a distorted square wave with leading and trailing edges which coincide with the leading and trailing edges of the input wave.



93. —Differentiating circuit—period time=2 R-C time.

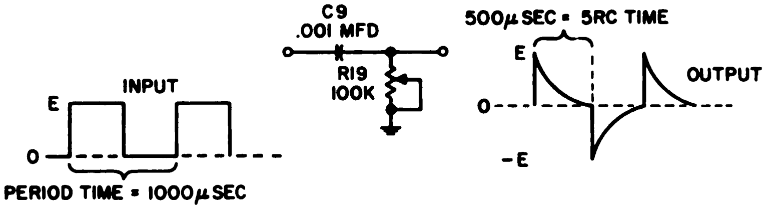
In the illustration, the period time was equal to 2 R-C time. The output waveform did not consist of sharp positive and negative spikes, such as those that are required for timing pulses in fire control radar equipments. Further shaping of the waveform would be necessary.

Seeing How the Differentiating Circuit Works (Continued)

Now suppose the potentiometer shaft has been turned so that the resistance of R19 is 100,000 ohms. The R-C time constant of the circuit would be 100 microseconds.

$$t = 100{,}000 \times .001 = 100 \text{ microseconds}$$
$$\text{or } t = (10^5)\,10^{-3} = 10^2 = 100 \text{ microseconds}$$

With the 1000-cycle square wave fed into the circuit, the ratio of the period time to the R-C time is 10 to 1. One-half cycle of the input wave would have a ratio of 5 to 1. During this one-half cycle, 5 R-C time, capacitor C9 will have charged to the full value of the input voltage and no voltage will appear across resistor R19.



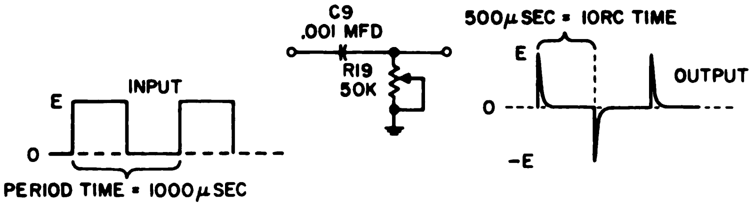
94. —Differentiating circuit—period time=5 R-C time.

You will notice that the edges of the output waveform begin at zero volts and rise to +E and drop to -E. This is because capacitor C9 is completely charged or discharged as the half-cycle ends. The output waveform contains more pronounced positive and negative spikes.

Now let the potentiometer be turned so that the resistance equals 50,000 ohms. The R-C time constant therefore equals 50 microseconds.

$$t = 50{,}000 \times .001 = 50 \text{ microseconds}$$
$$\text{or } t = (5 \times 10^4)\,10^{-3} = 5 \times 10 = 50 \text{ microseconds}$$

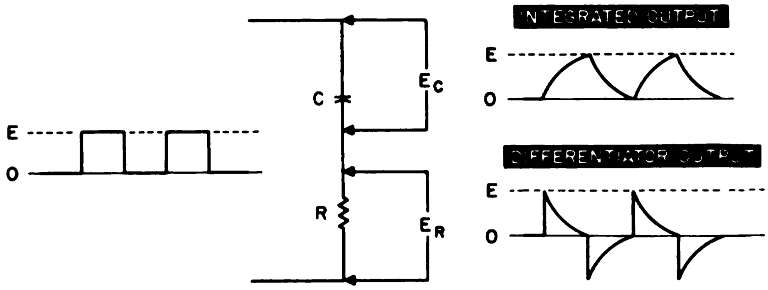
Since the time constant is now only one-tenth of the pulse width, the output from the differentiator consists of voltage spikes that are much sharper than before. Capacitor C9 charges to 63 percent of E within 50 microseconds. This leaves only 37 percent of E appearing across R19 at the end of 50 microseconds, 1 R-C time constant. At the end of 250 microseconds, the capacitor will have charged to the full input voltage and there will be no voltage across R19.



95. —Differentiating circuit—period time=10 R-C time.

Integrator and Differentiator Outputs

Since an R-C circuit has two components, there are always two voltage waveforms available in the circuit. The voltage across the resistor is the Differentiator output and the voltage across the capacitor is the Integrator output. An R-C circuit that has a short time constant is a good Differentiator, while a circuit that has a long time constant is a good Integrator.

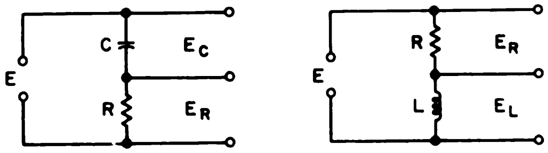


96. — R-C circuit outputs.

L/R Transients

A voltage divider containing inductance and resistance is used quite often in radar circuits. This voltage divider is known as an L/R circuit.

The operation of L/R circuits is similar to that of R-C circuits. In an L/R circuit, the current through the inductor-resistor rises exactly like the condenser voltage in an R-C circuit. With slight modifications, all of the waveforms obtainable in R-C circuits are obtainable in L/R circuits.



RC CIRCUIT L/R CIRCUIT

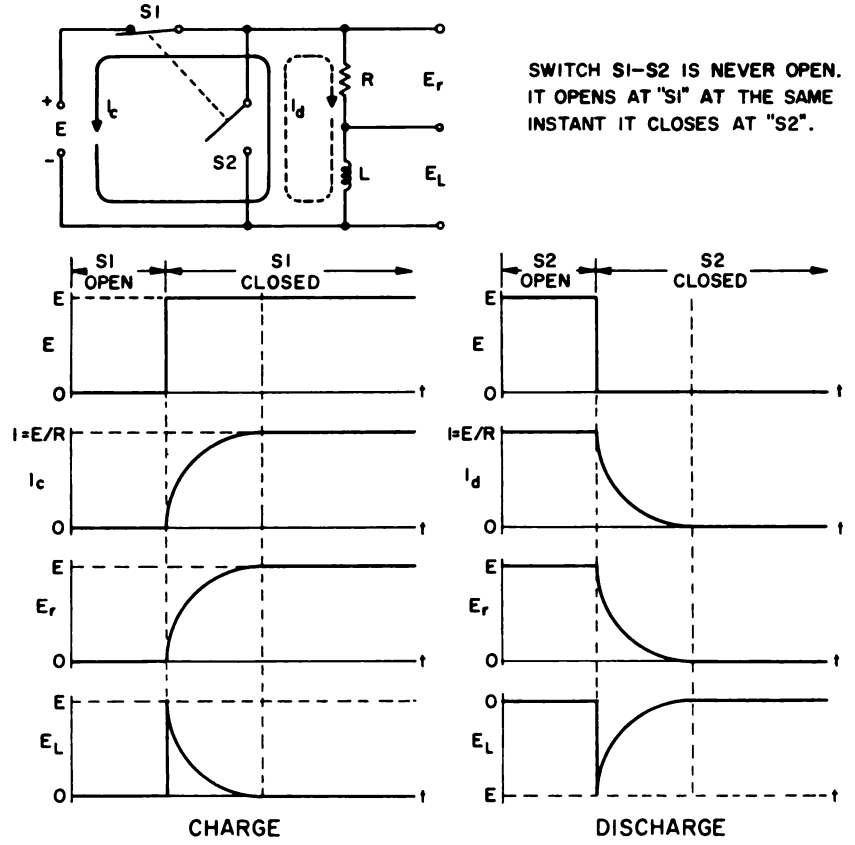
97. — Similarity of R-C and L/R circuits.

The significance of the time constant in L/R circuits is the same as that in R-C circuits. It is defined as the time required for the current through the inductor to increase to 63 percent of maximum current on the charge cycle and to decrease to 37 percent of maximum on the discharge cycle. The formula is t = L/R and the following expressions are often used:

t (in seconds) = L (in henrys) / R (in ohms)
t (in microseconds) = L (in microhenrys) / R (in ohms)

L/R Transients (Continued)

With S1 closed and S2 open, a voltage is applied across the voltage divider. A current attempts to flow, but the inductor opposes this current by building up a back EMF which, at the initial instant, equals the applied voltage. As current begins to flow, a voltage, E_r, appears across R and E_L is reduced by this same amount. Reduced voltage across the inductor results in less rapid increase in charge current (I_c) and the resistor voltage increases less rapidly. E_L finally becomes zero when the current stops increasing. E_r then equals the applied voltage.

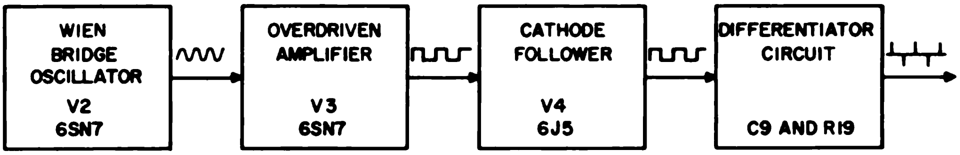


98.— Operation of an L/R circuit.

Now, assuming that S1 is opened and S2 is closed, the voltage across R will try to decrease to zero, but the inductor will oppose any change of current through it. At the instant the switches are operated, a voltage E is maintained across the resistor because of the action of the inductor and a negative voltage equal to -E must appear across L. The discharge current, I_d, decreases gradually and the voltage across the resistor decreases proportionately. Since E_r plus E_L is equal to zero at all times, the voltage across the inductor will also decrease. This action continues until E_r and E_L are both zero and there is no current flowing in the circuit.

Experiment—Test Setup

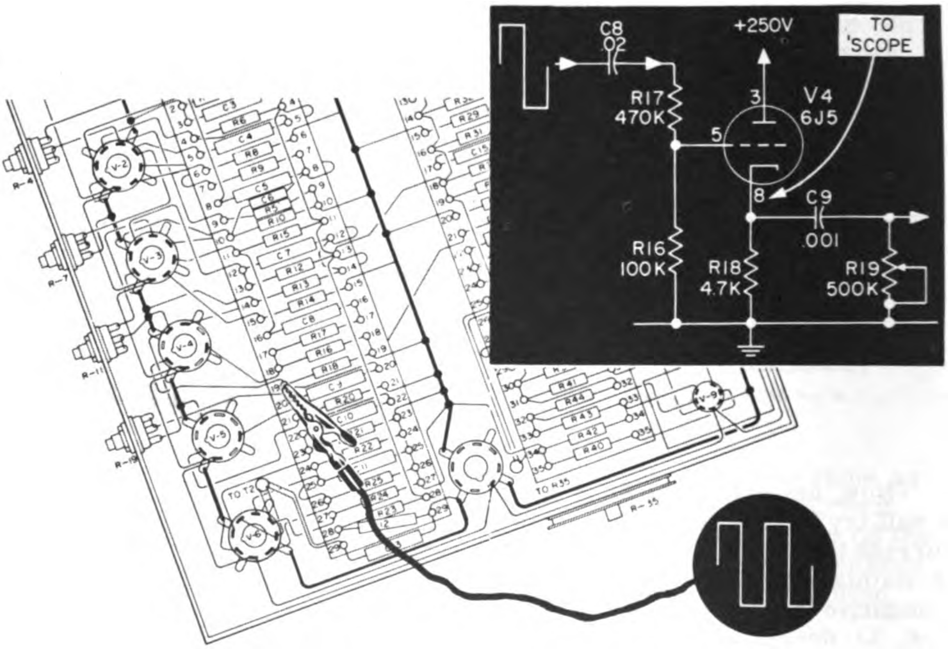
In this experiment, you will see how a resistance-capacitance circuit transforms a square-wave input into a series of positive and negative pulses. This action is called "differentiation," and the circuit is called a "differentiating circuit." You will vary the R-C time constant (by varying the value of R) and observe how the rate of differentiation is affected.



99.— Block diagram of a pulse-generating circuit.

The equipment needed for this experiment is a 'scope and multimeter.

To set up the circuits for observing differentiation, connect the oscilloscope test lead to the output of the cathode follower (A-19L). Adjust the Wien bridge and overdriven amplifier by setting R4 and R11 to maximum, and R7 for a good square wave. Be sure to set the 'scope attenuation control to as high a setting as possible and still be able to see at least a five-box-high peak-to-peak square wave. If the attenuation control is set too low, the 'scope input circuits may overload, with resulting distortion to the waveform under observation.



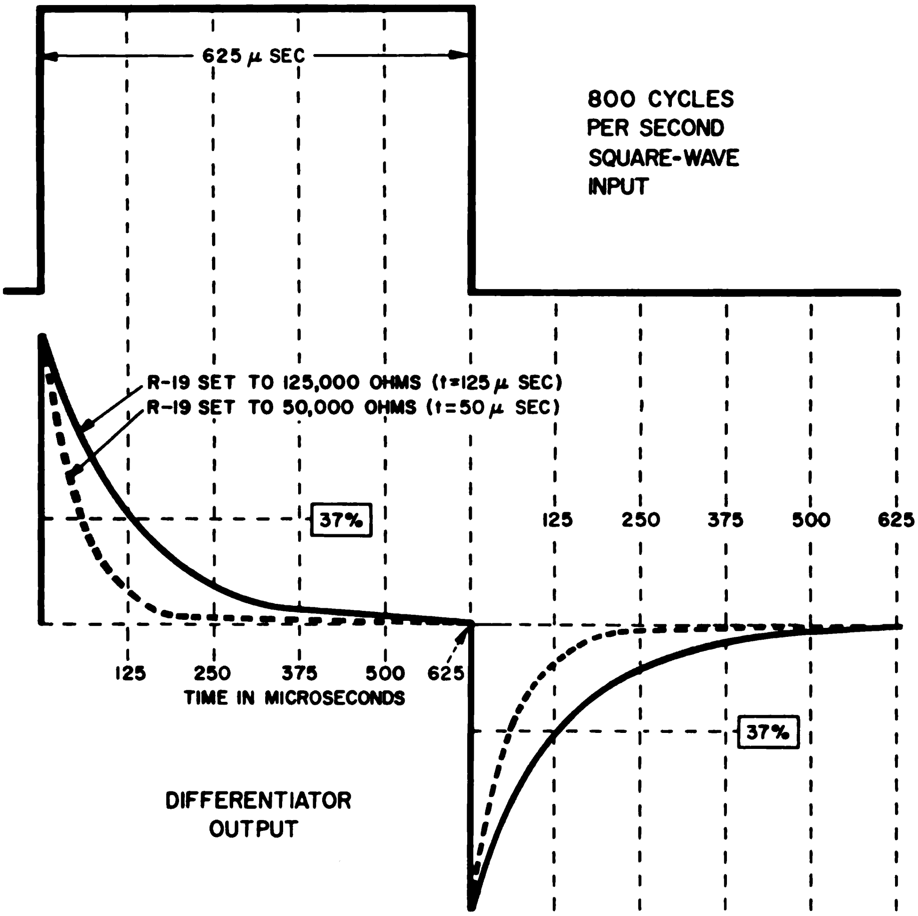
SET R4, R11 AND R19 TO MAXIMUM RESISTANCE..... ADJUST R7 FOR A SQUARE WAVE

100.— Differentiating circuit—test setup.

Experiment—Checking Waveforms; Short R-C Time Constant

For good differentiation, a "short" R-C time-constant circuit is required. This means that the time constant of the R-C circuit must be one-tenth (or less) of the time of one cycle of the input waveform. Since the frequency of the input square wave is determined by the Wien bridge oscillator, its frequency is about 800 cycles per second. The period time then is 1250 microseconds. The time constant of the R-C circuit should be 125 microseconds, or less, to give sharp pulses in the differentiator output. To obtain this time constant with C9 being .001 mfd would require that R19 be set to 125K ohms. To obtain even sharper pulses in the output, R19 may be set to 50K ohms. With this setting, the R-C time constant would be 50 microseconds.

In the chart shown below, you can see that, with R19 set at 125K ohms, you have a longer R-C time than with it set at 50K ohms. You can also see that the shorter R-C time produces a sharper voltage spike or trigger, which is the desired result in differentiating circuits.



101.—Effects of R-C time constants on differentiator output.

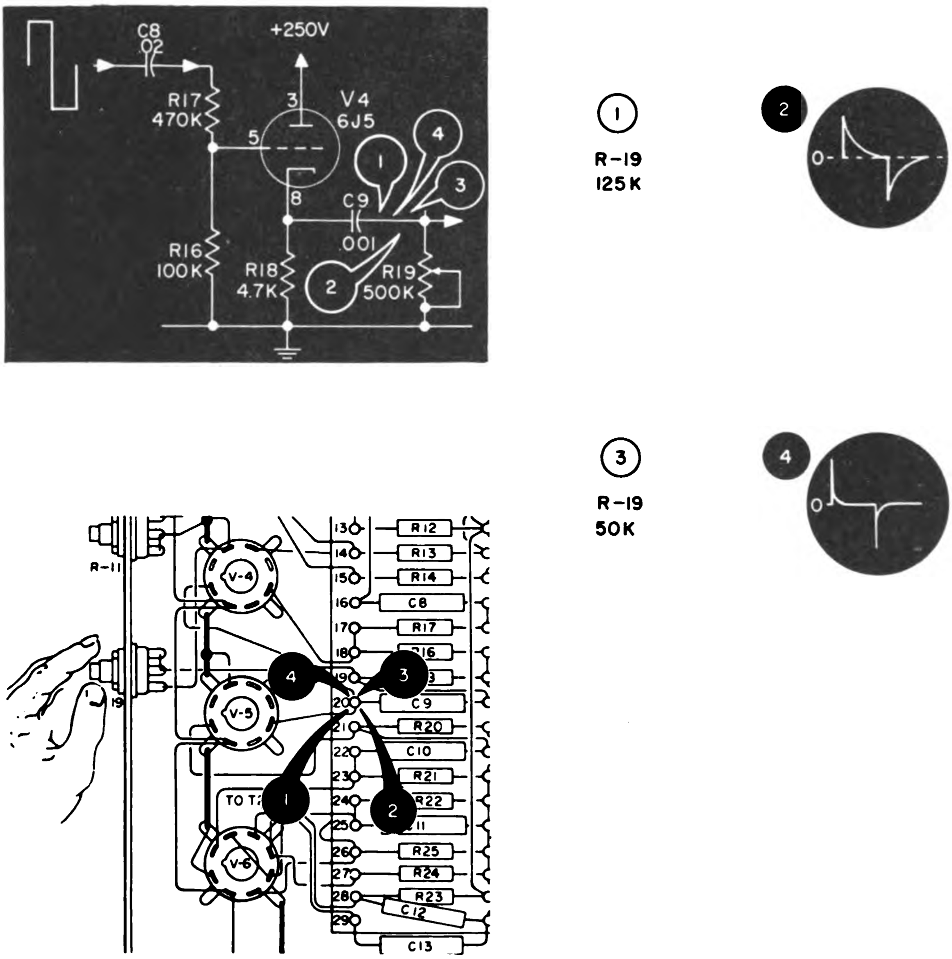
DIFFERENTIATING CIRCUITS

Experiment—Checking Waveforms; Short R-C Time Constant (Continued)

To establish a short R-C time constant for fast differentiation (Step 1) place an ohmmeter across R19 (between A-20L and chassis ground) and set R19 for a reading of 125K ohms. Then (Step 2) connect the 'scope to R19 at A-20L and apply power to the equipment. Observe the differentiated waveform and note that the voltage just returns to zero during one-half cycle of the square wave. Secure power to the chassis.

Now (Step 3), place an ohmmeter across R19 and chassis ground, and set R19 for a reading of 50K ohms. Apply power to the equipment and (Step 4) observe the waveform at R19 (A-20L). Note that the waveform returns to zero much sooner than when a large resistance was used for R19. Thus, much sharper pulses, or triggers, have been developed.

These sharp pulses, or triggers, will be encountered in the timing circuits of fire control radar equipments. Either the positive or negative pulse may be used. These pulses are used to initiate circuit actions to develop sweeps, to provide time delays, and to permit electronic switching.



102.—Differentiating circuit—checking R-C time constant.

DIFFERENTIATING CIRCUITS

Experiment—Trouble Shooting

Because the differentiating circuit consists of a resistor and capacitor, trouble shooting this circuit is elementary. About the only thing that can go wrong is that the capacitor or resistor will either short or open.

The symptom for an open capacitor in a differentiating circuit is a signal input but no signal output. Paralleling the suspected capacitor with a known good one will quickly verify the trouble.

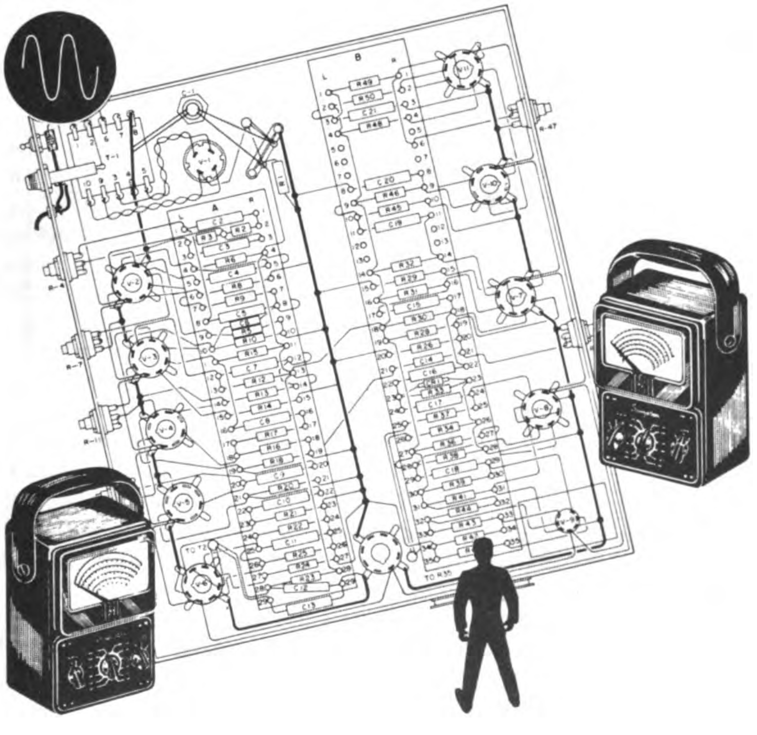
The symptom for a shorted capacitor is loss of differentiation with the input signal appearing unchanged across the output.

The symptom for an open resistor is usually a signal output without differentiation.

The symptom for a shorted resistor is usually no signal output.

You will now insert troubles into your partner's chassis and he in yours—anywhere in the circuits you have already tested. Be sure to get the instructor's ok before inserting the trouble. For fast and efficient trouble shooting, follow the logical trouble-shooting procedure that you have been using all along.

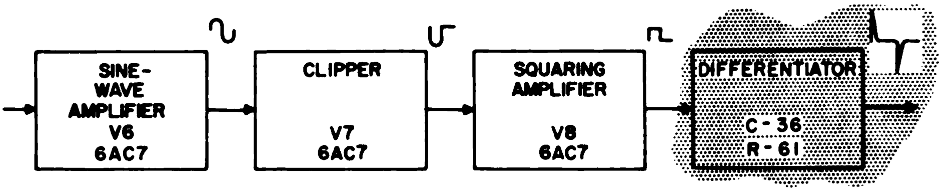
1. Signal-trace to isolate the trouble to a particular stage.
2. Voltage-check the stage to determine area of defect.
3. Resistance-check suspected area to isolate trouble to a particular component.



103.—Differentiating circuit— trouble shooting.

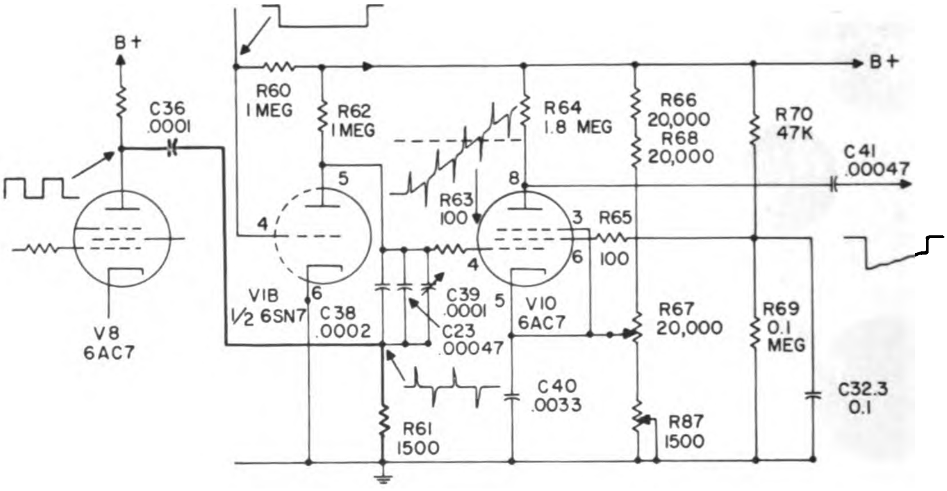
Applications—Differentiating Circuits

Let us look now at some specific applications of R-C differentiating circuits as found in fire control radar equipment. Several examples of differentiators may be found in each of these equipments. The first example is found in the ranging circuits of the Mark 34 and AN/SPG-34 radar equipments.



104.— Use of differentiator in Mark 34 and AN/SPG-34 Radars.

The period time of the sine wave is 12.2 microseconds. This means that the duration of one-half cycle of the square wave is 6.1 microseconds. C36 is .0001 mfd and R61 is 1500 ohms. The ratio of period time to R-C time is about 40 to 1. Sharp differentiated pulses, both positive and negative, occurring at 6.1 microseconds will be the output of the differentiating circuit.



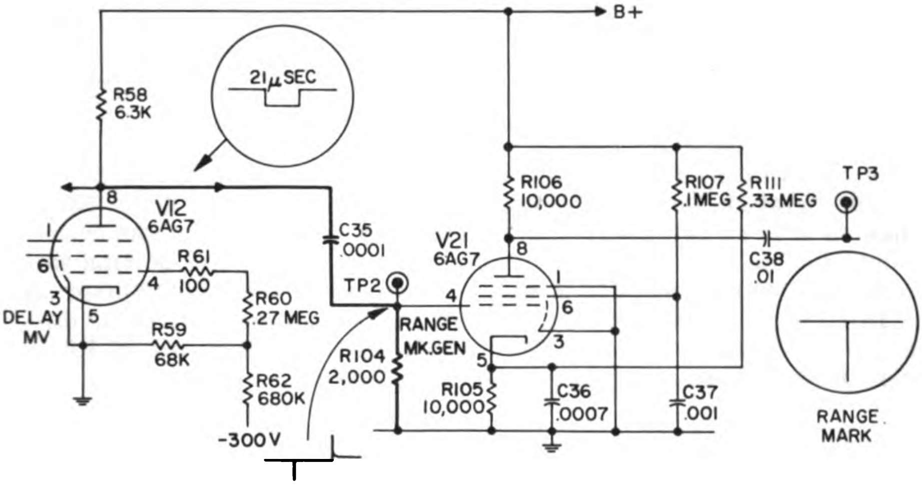
105.— Mark 34 Radar differentiating circuit.

Although both positive and negative pulses are the output of the differentiator, only the positive pulses can have any effect on the next stage. The next stage is biased below cut-off and the first positive pulse that raises the grid voltage above cut-off will produce a signal in the plate circuit. The bias on V10 is controlled by the settings of R67 and R87.

Applications—Differentiating Circuits (Continued)

The application of a differentiator, as shown on this page, is one which will be found in the Mark 25 Radar.

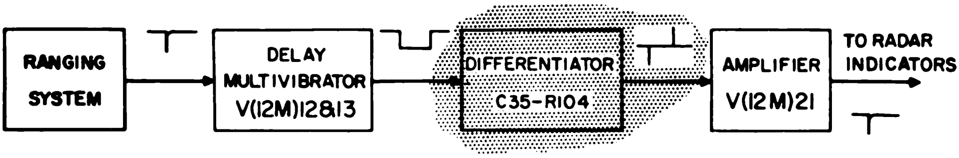
The input to the differentiator is a square wave from the plate of a multivibrator (V12) which is triggered by the output of the range unit. The output of the differentiator is applied to a tube called the range mark generator (V21).



106.— Mark 25 Radar differentiating circuit.

The range mark generator, V21, is normally cut off by the cathode bias derived from the voltage divider, R111 and R105. The negative 21-microsecond pulse on the plate of V12 is differentiated by capacitor C35 and resistor R104. A sharp negative and positive pulse are produced 21 microseconds apart, and applied to the grid of the range mark generator, V21. Since V21 is cut off, the negative pulse produced by the leading edge of the 21-microsecond square wave has no effect on the tube. The positive pulse produced by the trailing edge raises the grid above cut-off, and a sharp negative pulse appears in the plate which is delayed 21 microseconds from the range pulse. The range mark, after further amplification, is used as the movable range index on the radar indicators.

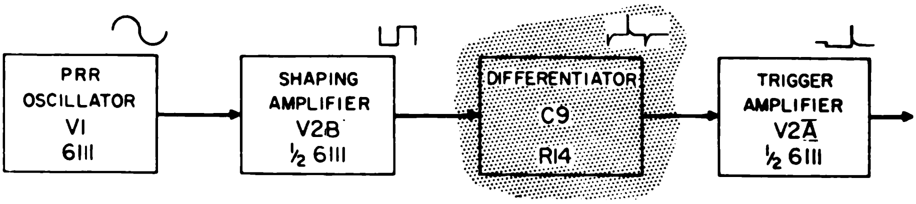
You may wonder why a 21-microsecond pulse could not be used. If a pulse 21 microseconds wide were used as the range mark, you would have great difficulty in determining the precise range, since 21 microseconds is equal to more than 3400 yards. Through the use of a differentiator, a very sharp voltage spike will be produced which will provide a very sharp mark on the screen of the radar indicators. This will make range determination by the operator very easy.



107.— Use of differentiator in Mark 25 Radar.

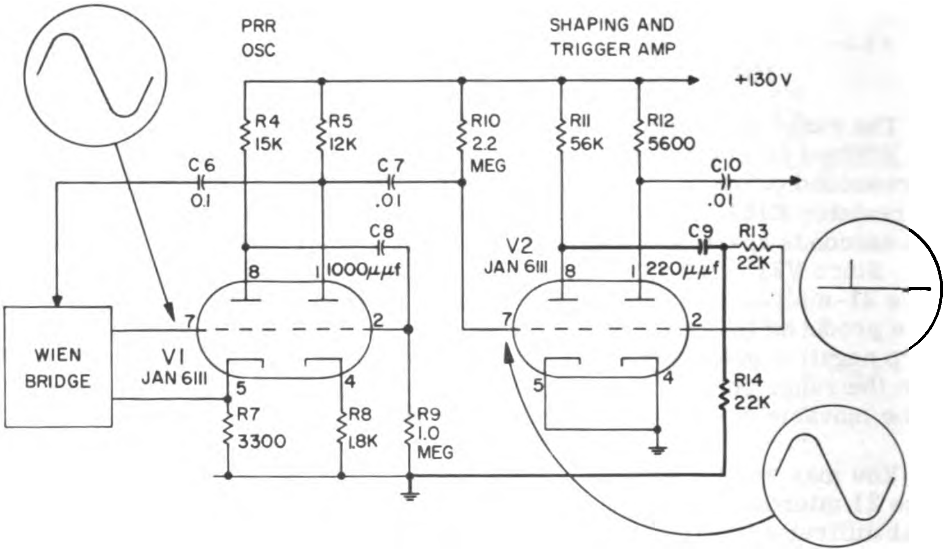
Applications-Differentiating Circuits (Continued)

The next example of a differentiating circuit is from Radar Equipment AN/SPG-50. The differentiating circuit is just a part of the schematic shown here. The remainder of the schematic provides an excellent review of other circuits that you have studied.



108. — Use of differentiator in AN/SPG-50 Radar.

The output of the PRR (Pulse Repetition Rate) oscillator, a Wien bridge oscillator, is fed to the grid of the shaping amplifier, V2B. This tube has its grid circuit connected to +130 volts through R10. The negative portion of the sine wave will cut off V2B and the positive portion will drive the tube into saturation. A square wave is produced in the plate circuit. This square wave, having a comparatively long period time, is differentiated by R14 and C9. The R-C circuit has a time constant of 4.8 microseconds and provides sharp differentiation.



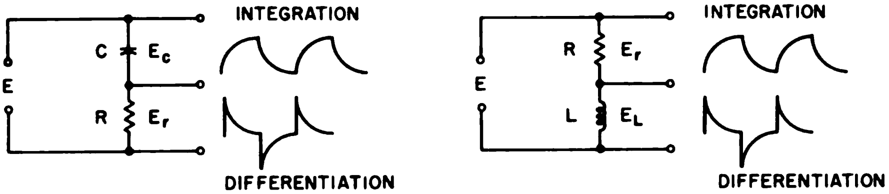
109. — AN/SPG-50 Radar differentiating circuit.

R13, in the grid circuit of V2B, gives grid current limiting on the positive differentiated pulses, thus eliminating them. The negative pulses are amplified and inverted in the tube, giving positive pulses in the output of V2B. These positive pulses initiate the timing for the radar equipment.

DIFFERENTIATING CIRCUITS

Review

In this topic, R-C circuits have been discussed in some detail. If you have studied this topic, and understand the principles discussed here, you will find your study of radar circuits will be much easier. Remember, you can always use this section as a ready reference.



110.—R-C and L/R circuits—review diagrams.

Listed below are some of the facts that you should have learned in this topic.

1. If the R and C or L and R values are known, you can determine the time constant of the circuit.
2. If the time constant is known, the percentage of voltage appearing across the capacitor, resistor, or inductor may be determined by the universal time-constant chart.
3. With the universal time-constant chart, the exact voltage, at any time, across the circuit components can be determined if the magnitude of the impressed voltage is known.
4. If the R-C or L/R time constant is ten or more times greater than the period time of the applied voltage, the time is "Long."
5. If the time is one-tenth (or less) of the period time, it is "Short."
6. It requires several time constants for an R-C or L/R circuit to reach its normal operating level.
7. How to compute R-C and L/R time.
8. How to compute Period time.
9. In an L/R circuit, the resistor waveform varies as the capacitor waveform in an R-C circuit.
10. In an L/R circuit, the inductor waveform varies as the resistor waveform in an R-C circuit.
11. Differentiation occurs across the resistor in R-C circuits.
12. Integration occurs across the capacitor in R-C circuits.
13. Differentiation occurs across the inductor in L/R circuits.
14. Integration occurs across the resistor in L/R circuits.
15. Sharp differentiation occurs in circuits having a "Short" time constant as compared to the period time.
16. The output of a differentiator, sharp positive and negative pulses, is used to trigger the next stages.

Did you observe that, in the applications of differentiating circuits, the final output was always a sharp positive or negative spike? Later, in your study of specific fire control radars, you will find that the input waveform is almost always a square wave or a square pulse of voltage. Only a very few applications were presented. However, you will find R-C differentiating or integrating circuits used in great numbers throughout all fire control radar equipments. L/R circuits are used less frequently.

TOPIC 6: LIMITING CIRCUITS—DIODE TYPE

Diode Limiters—General Purpose

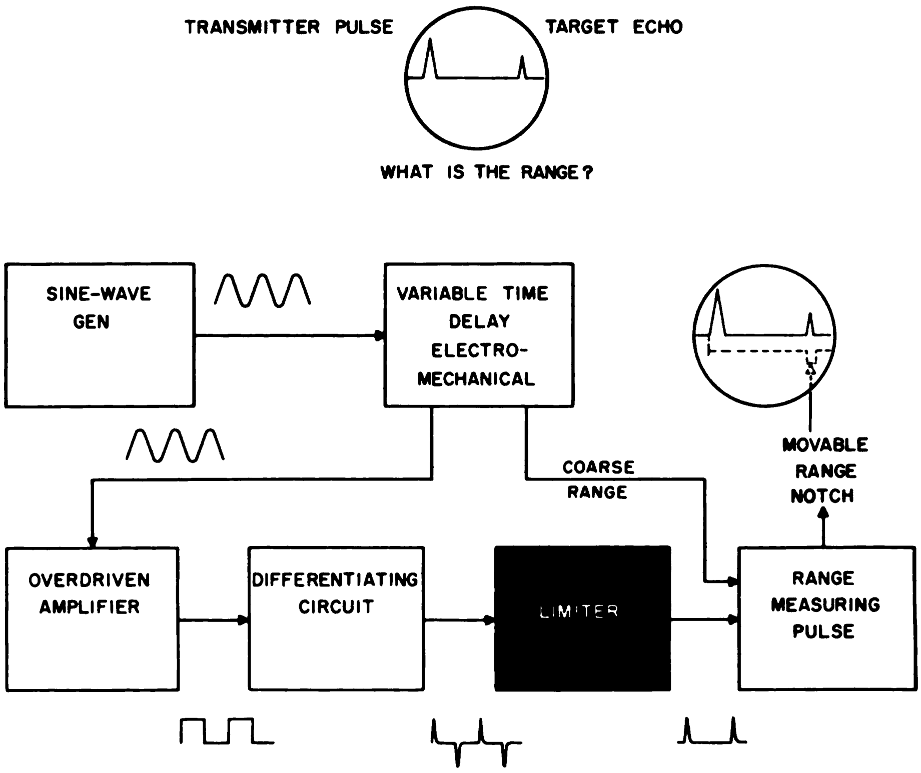
In your study of overdriven amplifiers and differentiating circuits, you found that essentially they were used to shape a waveform which could be readily used in other circuits.

In this topic, you are going to study another type of shaping circuit which is called a diode limiter, or clipper. The diode limiter is used to limit or clip either the positive or negative portion of a waveform.

As you may recall from your earlier studies in "Basic Electronics," this same principle was utilized in the second detector of your "Superhet" radio. There you clipped the negative portion of the signal and the positive portion was delivered to the amplifier stage as audio.

The diode limiter is usually encountered just ahead of a stage that requires one signal polarity to trigger it, but which might be made unstable if a signal of opposite polarity is also applied.

One important application of diode limiters is in the Range Determination system of fire control radars. They will also be encountered elsewhere in these equipments.

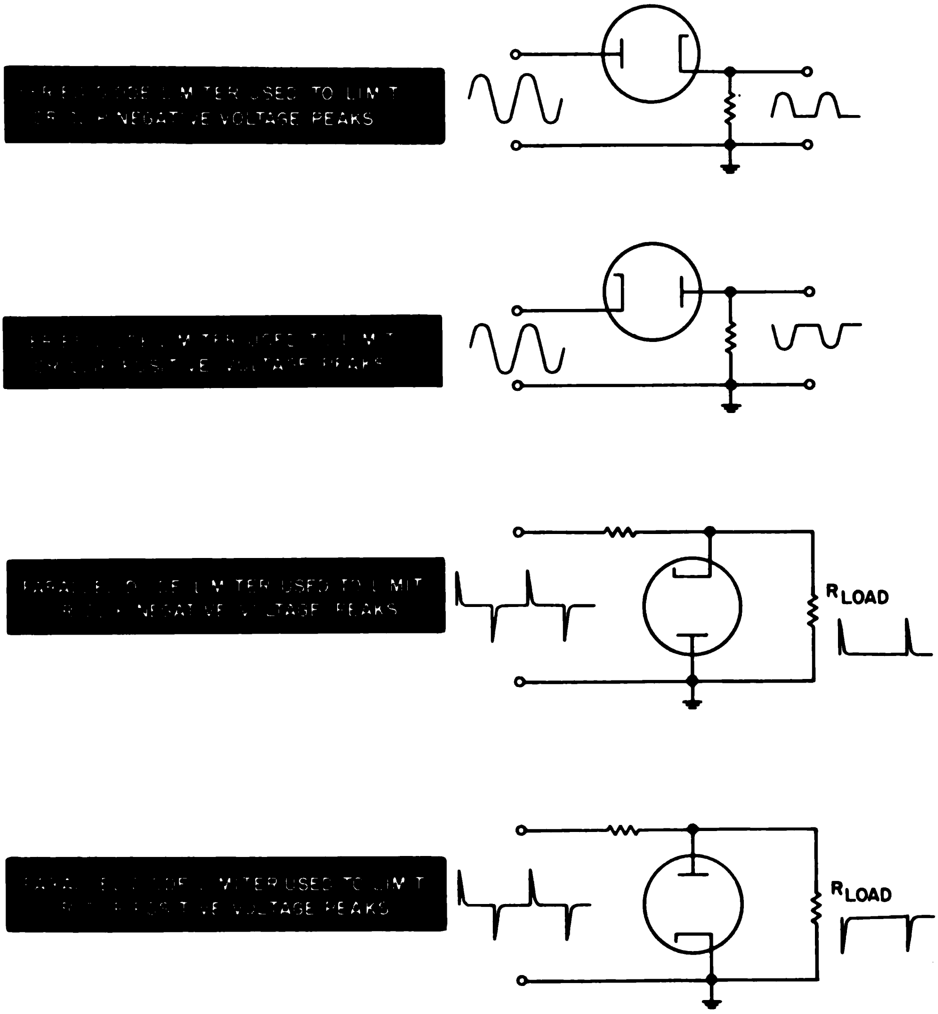


111.—The diode limiter.

LIMITING CIRCUITS—DIODE TYPE

The Diode Limiter—A Shaping Circuit

The simplest form of the limiting circuit is the diode limiter. The circuit consists of a diode and a single resistor. Surprisingly enough, these two components can be connected in four different ways to form four distinct diode limiters, as shown below.


SERIES DIODE LIMITER USED TO LIMIT PORTION OF NEGATIVE VOLTAGE PEAKS
SERIES DIODE LIMITER USED TO LIMIT PORTION OF POSITIVE VOLTAGE PEAKS
PARALLEL DIODE LIMITER USED TO LIMIT PORTION OF NEGATIVE VOLTAGE PEAKS
RLOAD
PARALLEL DIODE LIMITER USED TO LIMIT PORTION OF POSITIVE VOLTAGE PEAKS
RLOAD

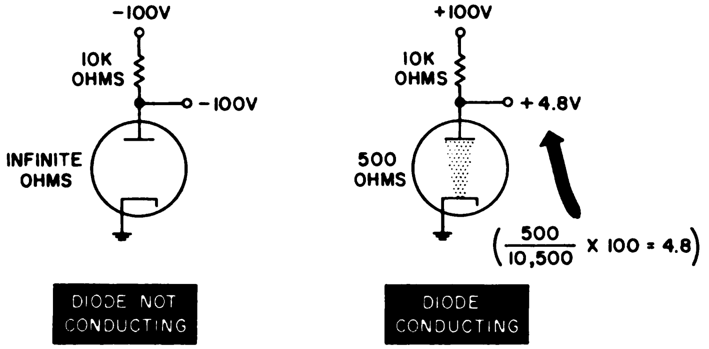
112.— Uses of diode limiters.

The input to a diode limiter circuit may be a sine-wave signal or positive and negative differentiated pulses. The portions of the input signal that will be limited will be determined by the circuit wiring.

LIMITING CIRCUITS—DIODE TYPE

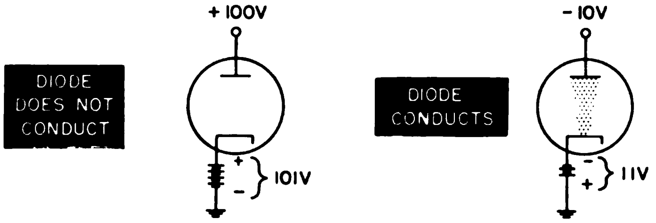
The Principles of Diode Limiting

There are two basic facts which you must understand before you can go into the details of diode limiting circuits. First, the resistance between the plate and cathode is practically infinite when no current is flowing, but it drops to approximately 500 ohms when current is flowing.



113.—The diode limiter as a voltage divider.

The diode limiter circuit has a number of variations, but in each of these the diode is in series with a resistor. What you have here is a voltage divider circuit consisting of a fixed resistor of the order of 10K ohms, in series with a diode whose resistance may be infinite or 500 ohms. When the diode does not conduct, all of the input voltage is across the diode and none across the resistor. When the diode does conduct, the voltage divides across 10K and 500 ohms—which means that the voltage across the fixed resistor will be 20 times greater than the voltage developed across the diode.

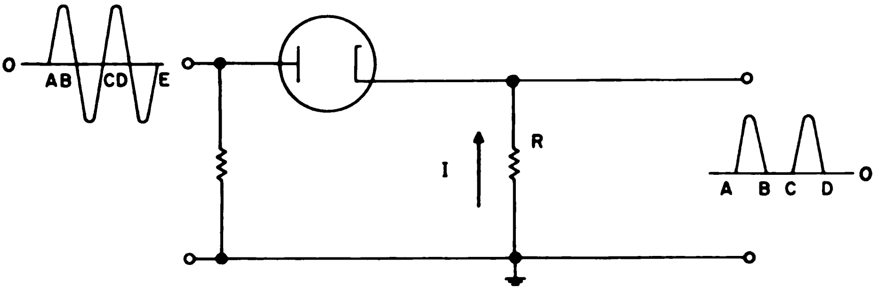


114.—Conduction in a diode limiter.

The second basic fact that must be understood is that the diode will conduct only when the plate is positive with respect to the cathode. If the plate is +100 volts and the cathode is +101 volts relative to ground, the plate is -1 volt relative to the cathode and the diode will not conduct. Similarly, if the plate is -10 volts and the cathode is -11 volts relative to ground, the plate is +1 volt relative to the cathode and the diode will conduct. All of the diode limiters you will study make use of this principle, and several of these circuits involve the use of biasing on either the plate or the cathode.

Operation of a Typical Diode Limiter

Before you actually start to work with these limiting circuits, go through the following description of how a typical diode limiter works.



115.—A typical diode limiter.

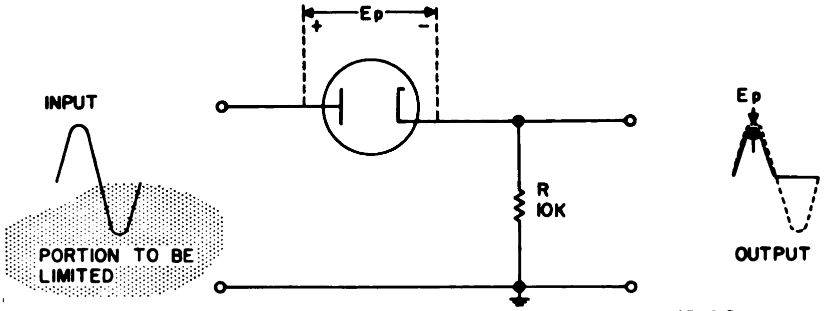
As shown above, a sine-wave voltage is applied to the limiter circuit. The cathode of the diode is at ground potential at time A, since there is no current flowing through R. From time A to time B, the voltage on the plate of the diode causes it to conduct. The current I flows from ground through the resistor R to the cathode of the diode and from the cathode to the plate. This current assumes the waveform of the applied voltage which causes it to flow, and develops a corresponding voltage across resistor R. From time B to time C, the plate of the diode is negative with respect to the cathode. This means that there is no current flow through the tube and no voltage developed across R. Thus, the limiter has passed the positive peak but not the negative peak. The tube does not conduct until time C and then only for the period C-D, allowing another positive peak to be developed, but not a negative peak. From the above, you can see that the action of the diode limiter depends upon the diode conducting for only a portion of the cycle of the input waveform. In a series diode limiter, the limiting takes place while the diode is not conducting. As you will see later, the opposite is true for the parallel limiter.

A comparison of the input and output waveforms of the diode limiter circuit above shows the shaping action of a limiter circuit. The negative portion of the sine-wave input has been limited. Normally, further shaping of the waveform is necessary. The waveform might be applied as the input to one overdriven amplifier stage, which could easily produce a square-wave output.

The output of a differentiator is often applied to a limiter circuit. The limiter, depending upon the arrangement of circuit components, limits either the positive or negative pulse. The remaining pulse is used to trigger the circuit that follows. If the output of the differentiator is applied to the limiter circuit shown above, the output of the limiter circuit would be positive pulses. These positive pulses are used to initiate the circuit action of the succeeding stage. This is the action that will be performed by the limiter circuit in your chassis. The positive output pulse from the limiter is used to trigger the next stage.

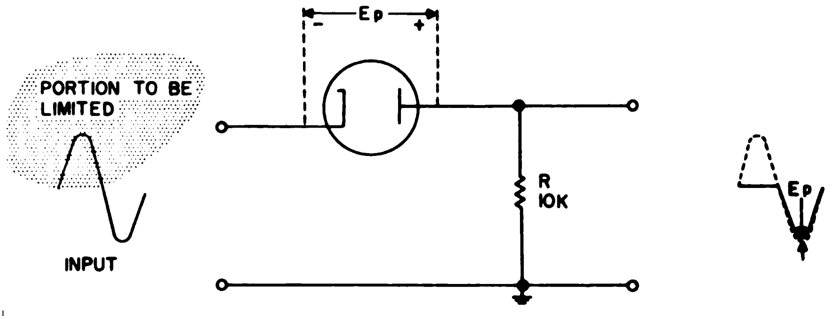
The Series Diode Limiters

In the case of the series diode limiters, the output voltage is taken from across a resistor that is in series with the diode. In the series limiter for clipping negative peaks, the input voltage is applied to the plate of the diode. When this voltage is positive, the diode conducts and the resultant current flow reproduces the positive voltage across the resistor. The amplitude of this output voltage is equal to the input voltage less E_p, the very small voltage drop across the tube. About twenty times more voltage is across R than across the diode, and E_p is about one-twentieth of the input voltage.



116.—Series diode limiter for limiting negative peaks.

When the circuit is to be used to clip positive peaks, the diode connections are reversed. In this case, the input voltage is applied to the cathode of the diode. When the input is negative with respect to ground, the diode conducts, since its plate is at ground and consequently positive with respect to the cathode. This causes current to flow through the resistor to ground. This current reproduces the negative swing of the input across resistor R. Again, the amplitude of the output voltage is equal to the input amplitude less E_p, the drop across the tube when it is conducting.



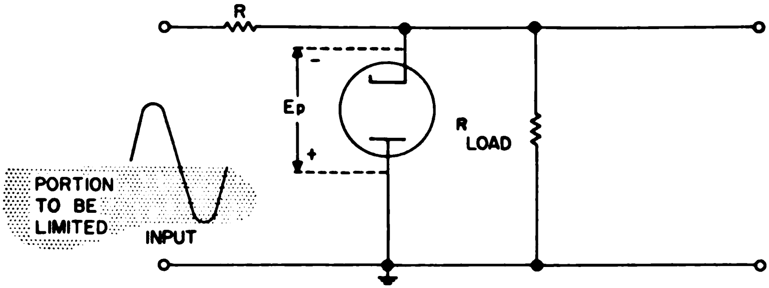
117.—Series diode limiter for limiting positive peaks.

A series diode limiter is one in which the output is taken across the resistor.

LIMITING CIRCUITS—DIODE TYPE

The Parallel Diode Limiters

Note that in the parallel limiters, when the diode conducts, it effectively reduces the resistance of R_{Load} to the low resistance of the diode. Therefore, almost all of the input voltage is eliminated since it is dropped across R. When the diode is not conducting, it no longer shunts R_{Load} and only the ratio of R to R_{Load} will determine the amount of the output voltage of the limiter circuit.

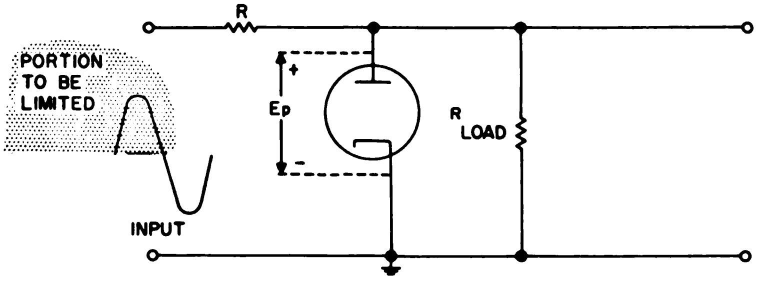


118.—Parallel diode limiter for limiting negative peaks.

In the parallel limiter for clipping negative peaks, the input voltage is applied across the tube circuit. The output voltage is taken from the cathode and the plate is grounded.

On the positive half-cycle, the diode will not conduct because the cathode is positive relative to the plate. Thus, the positive half-cycle will be reproduced in the output.

On the negative half-cycle, the diode will conduct and will eliminate nearly all of the negative half-cycle of the input waveform. Since the diode has a very low resistance when conducting, there will be some voltage drop across the tube which is called E_p. Thus, the negative peak is not clipped at ground level but at E_p volts below ground.



119.—Parallel diode limiter for limiting positive peaks.

In the parallel diode limiter for clipping positive peaks, the diode connections are reversed and the output waveform is the reverse of that of the parallel limiter used to eliminate the negative peaks.

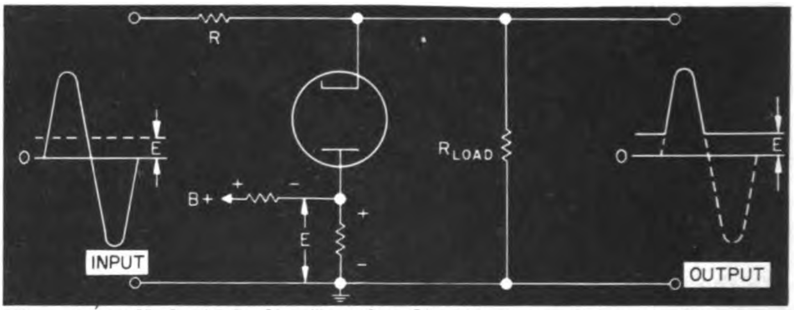
A parallel diode limiter is one in which the output is taken across the diode.

Parallel Diode Limiters with Positive Bias Voltage

By inserting a positive bias voltage in series with the plate or cathode of the diode of a parallel limiter, it is possible to limit all of the input waveform below a certain positive value or all of the input waveform above a certain positive value. Biasing voltage may be obtained from a tap on a voltage divider across the positive voltage supply.

If you put a positive voltage between the plate of the diode and ground in a parallel limiter for clipping negative peaks, any portion of the input below the value of this bias is clipped. This is true since any voltage below the bias value on the cathode allows the tube to conduct.

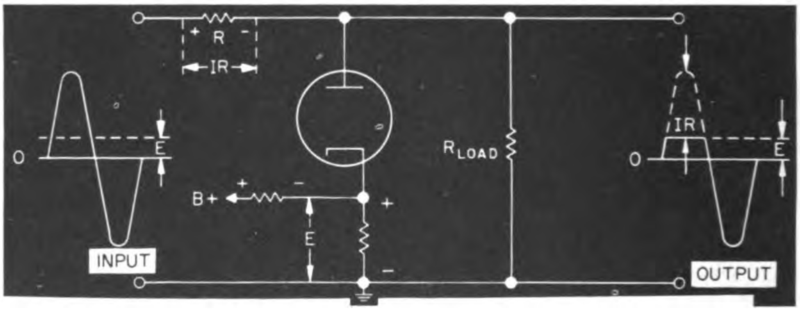
PASSES POSITIVE PEAKS



120.—Parallel diode limiter for limiting negative peaks.

If the diode connections are reversed and the positive bias is placed between the cathode and ground, any portion of the input above the value of the bias will be limited. This is true, since the cathode is at +E volts, so that the tube will conduct when the voltage on the plate exceeds +E volts. In this case, the difference between the input and output voltages appears as an IR drop across the resistor R, neglecting E_p, the drop across the tube.

CLIPS POSITIVE PEAKS



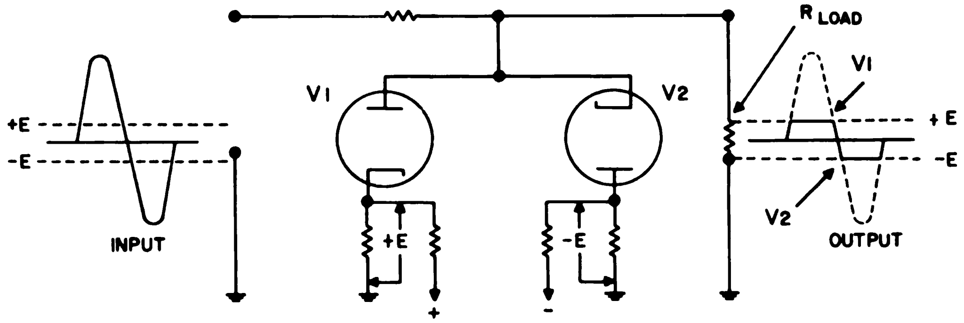
121.—Parallel diode limiter for limiting positive peaks.

If a negative bias voltage were inserted in series with the plate or cathode of a parallel limiter, all of the input waveform below a certain negative value or all of the input waveform above a certain negative value could be limited or clipped in the output. Negative bias voltages may be obtained from a tap on a voltage divider connected across the negative voltage supply.

Double-Diode Limiters

The double-diode limiter can be used to limit both the positive and the negative voltage peaks of a signal. It consists of two biased diodes connected in parallel, as shown below. Diode 1 has its cathode biased positive with respect to ground, and diode 2 has its plate biased negative with respect to ground.

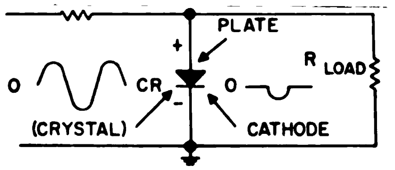
This circuit operates on the same principles as the biased parallel diode limiters explained on the previous page. As soon as the input voltage reaches a higher voltage than the positive biasing voltage, diode 1 conducts, Therefore, the positive swing is limited to the positive bias voltage. Diode 2 conducts when the input voltage is more negative than the negative bias voltage. Therefore, the negative swing is limited to the negative bias voltage. By use of the double-diode limiter, the positive and the negative swings of the input signal may be clipped to any desired level.



122. — Double-diode limiter.

Crystal Diode Limiters

The semiconductor diode has come into greater use for limiting circuit applications. Normally, these diodes consist of a small piece of germanium or silicon in which a rectifying junction has been formed. They act the same as a vacuum tube diode does, presenting a high resistance to current flow in one direction and a low resistance to current flow in the other. The semiconductor diode is more efficient than a vacuum tube diode, however. Furthermore, it requires no heater power and may be used in any of the diode limiter circuits previously discussed. The one illustrated is used in limiting the positive portion of the input wave.



123. —Semiconductor diode.

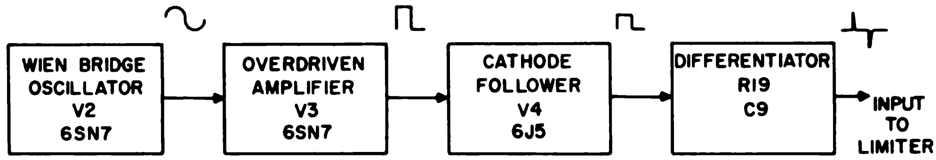
The schematic symbol of a semiconductor diode is shown in the figure to the left. This diode conducts when the arrow is positive with respect to the cathode symbol. When the signal is positive, the diode offers little resistance, and the signal is clipped. The negative swing is reproduced in the output due to the very high resistance encountered when the signal polarity is reversed across the semiconductor diode. Notice that this circuit functions in the same manner as a parallel vacuum tube limiter.

LIMITING CIRCUITS—DIODE TYPE

Experiment—Series Diode; Test Setup

In this experiment, you will observe how a series diode limiter can clip either the negative or positive portion of the differentiated square wave.

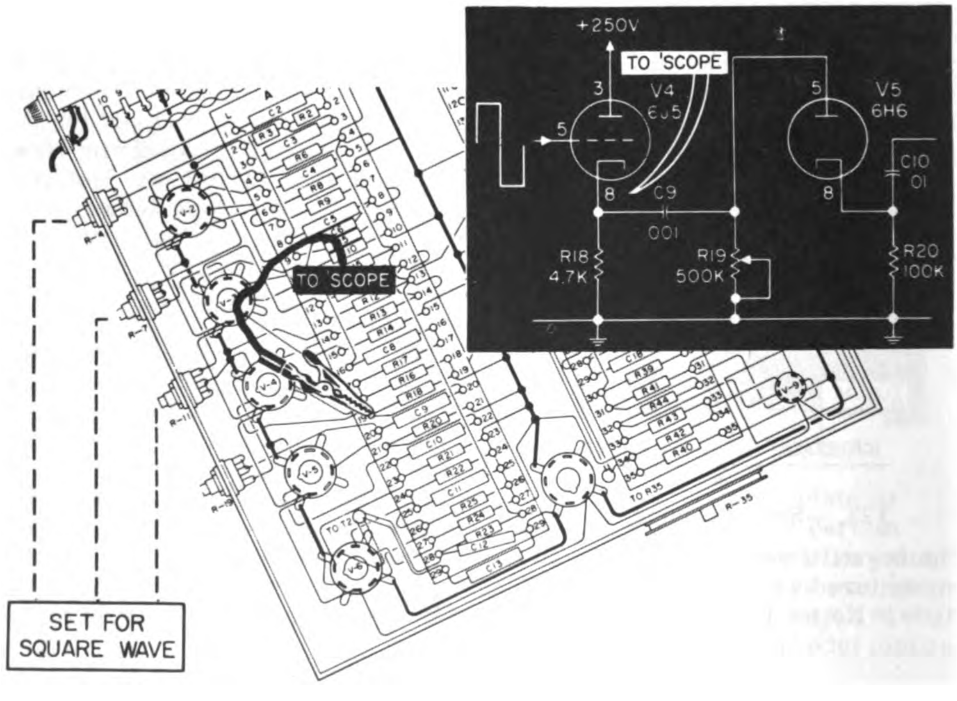
The Wien bridge oscillator will be used as the signal source for this experiment. The sine-wave output of V2 is shaped into a square wave by the overdriven amplifier. The cathode follower couples this square wave to the R-C differentiator, composed of R19 and C9. The positive and negative differentiated pulses are applied to V5. When V5 is operating as a negative diode limiter, the negative pulses will be eliminated from the output of V5, leaving only the positive pulses.



124.— Block diagram of a pulse-generating circuit.

The equipment required for this experiment is a 'scope, a multimeter, and a 6H6 tube.

To set up the input signal to the limiting circuit, connect the 'scope probe to the cathode pin 8 of V4. Apply power to the chassis and 'scope, and adjust R4, R7, and R11 to produce a good square wave.



125.—Series diode limiter— test setup.

LIMITING CIRCUITS—DIODE TYPE

Experiment—Negative Diode Series Limiter

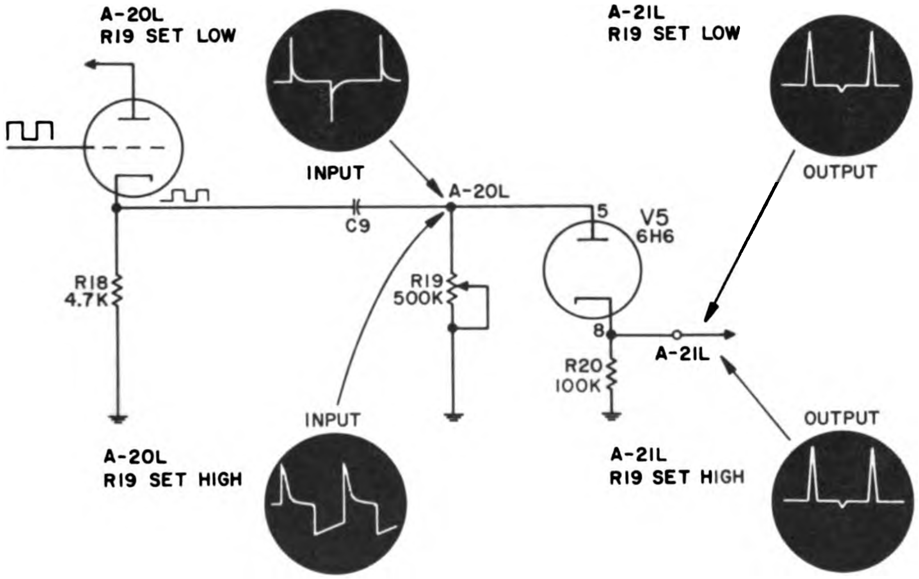
1. Insert 6H6 in V5 socket.

2. Set controls for a sharply differentiated waveform at pin 5 of V5.

3. Connect 'scope probe to pin 8 of V5 and note that the negative portion of the differentiated waveform is limited, while the positive portion is reproduced in the output.

This indicates that the diode does not conduct on the negative portion of the applied waveform. Thus, no voltage drop occurs across the resistor R20 and the negative waveform is eliminated.

However, when the signal goes positive, the tube does conduct and the resulting current through R20 reproduces the positive voltage waveform in the output.



126. — Series diode limiter— checking negative limiting.

Now set R19 to high value, so that the R-C time of C9 and R19 is long. Observe waveform at pin 5 of V5, then repeat step 3 above.

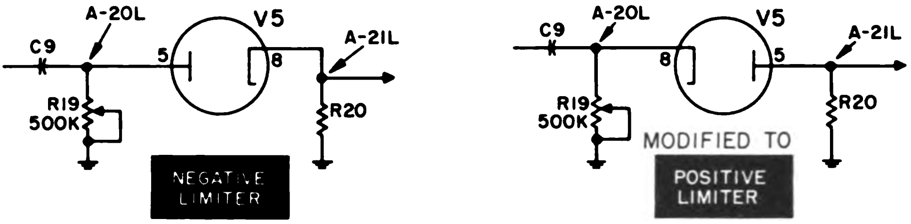
Note with R19 set at a high resistance, the R-C time of R19 and C9 is long. However, when V5 conducts, it effectively places R20 in parallel with R19 and decreases the R-C time. Thus, some differentiation occurs when the tube conducts. Compare the positive portion with the negative portion of the input waveform. Notice that when the diode does not conduct there is very little differentiation of the negative portion of the applied waveform, since R20 is no longer paralleled with R19.

LIMITING CIRCUITS—DIODE TYPE

Experiment—Positive Diode Series Limiter

You are now going to modify your chassis so that you will have a positive diode limiter circuit.

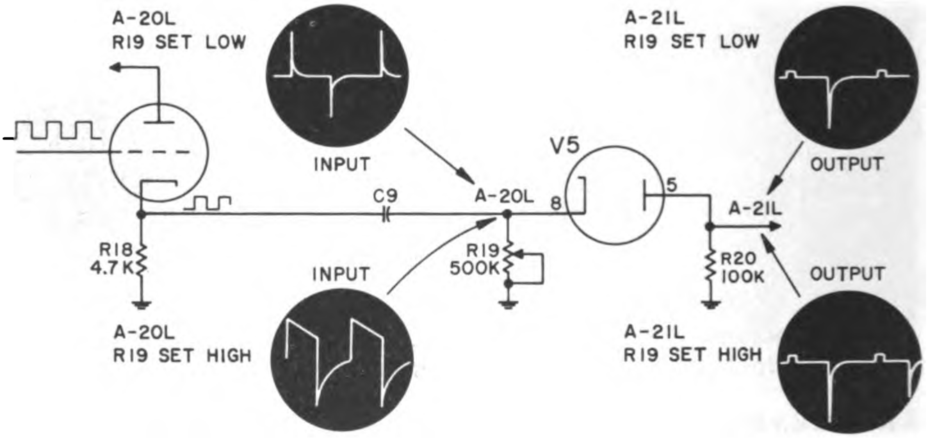
(1) Remove power from the chassis. (2) At A-20L, remove the lead from pin 5 of V5. (3) At A-21L, remove the lead from pin 8 of V5. (4) Connect the lead from pin 5 to A-21L. (5) Connect the lead from pin 8 to A-20L.



127.— Coversion of series diode from negative to positive limiter.

Your limiter circuit is now modified so that it will remove the positive portion of the applied waveform.

Apply power to the chassis. Now set your controls for a sharply differentiated waveform at the cathode (pin 8) of V5. Connect 'scope probe to pin 5 (plate) of V5 and note that the positive portion of the waveform has been limited, while the negative portion has been reproduced in the output.



128.—Series diode limiter—checking positive limiting.

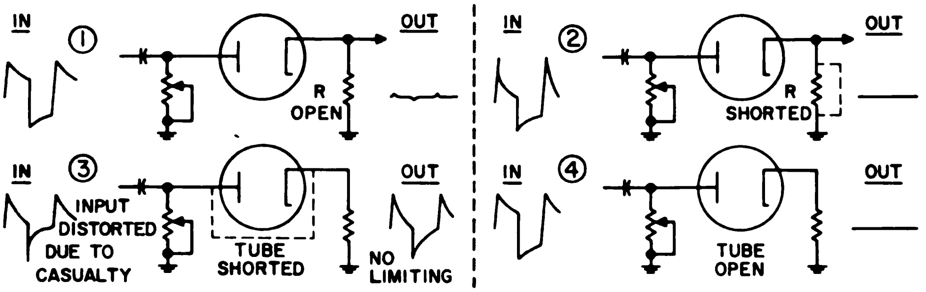
Now set R19 to a high value, and note that the input waveform has some differentiation on the negative portion and practically none on the positive portion. This is the same action you should have noted in the negative limiter. Can you explain why this occurs?

Rewire V5 as a negative diode limiter.

Diode Limiters—Trouble Shooting

The diagrams on this page indicate, generally, the waveforms that may be encountered in either series or parallel diode limiter circuits when the indicated component is faulty. As you can see, trouble shooting these circuits is not complicated and a few moments of thought will usually lead you to the trouble. However, as in all trouble-shooting procedures, signal tracing, voltage, and resistance measurements will lead you to the faulty component.

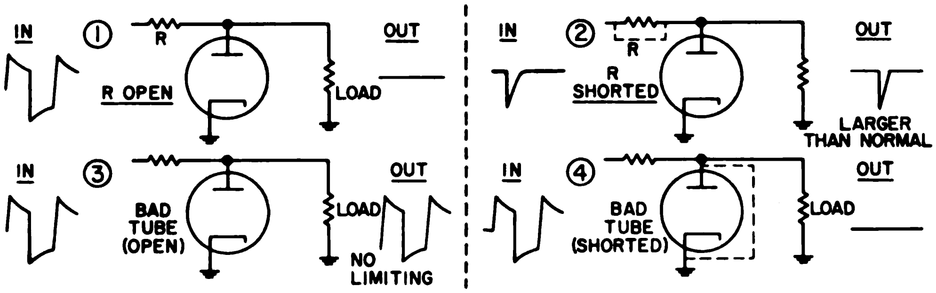
Series Diode Limiters—Trouble and Indications



129.—Series diode limiter— trouble shooting.

Notice if the resistor is open (diagram 1) that the output will be small. If the series resistor is shorted (diagram 2), there will be no output and the input is distorted. If the tube is shorted (diagram 3), the input will be distorted and the output will not be limited. In diagram 4, showing the tube open, there will be no output.

Parallel Diode Limiters—Trouble and Indications



130.—Parallel diode limiter— trouble shooting.

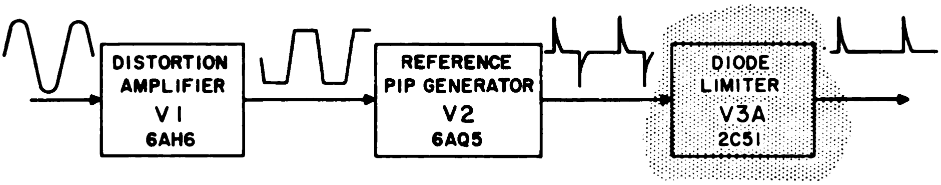
Notice that, in the parallel diode limiters, an open resistor or shorted tube will eliminate any signal from appearing in the output (diagrams 1 and 4).

Also, notice that with a shorted series resistor (diagram 2) that the output will be the same as the input. However, if the tube is an open circuit (diagram 3), there will be no limiting and the entire waveform will be reproduced.

You will now insert casualties in the negative limiter circuit of your partner's chassis.

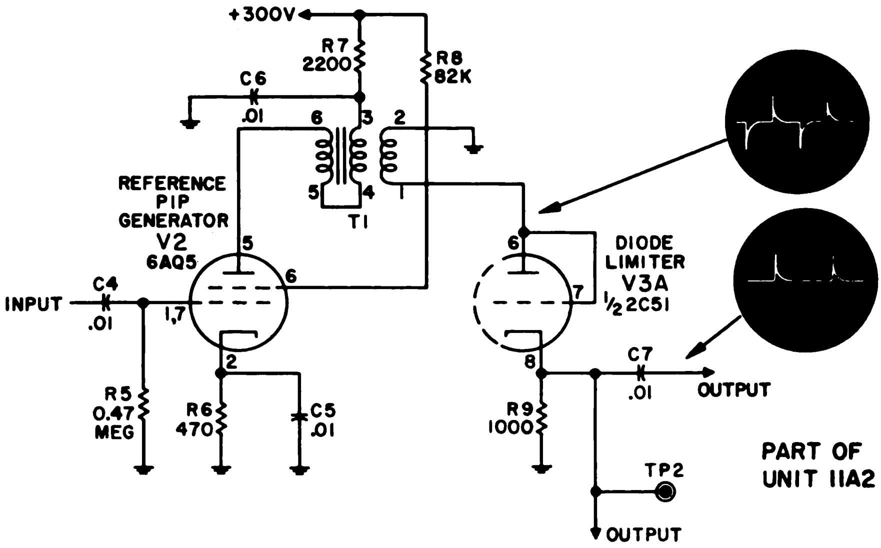
Applications—Diode Limiters

Diode limiters are used throughout fire control radar systems. Either positive or negative diode limiters, parallel or series, may be used. The limiter used in a particular circuit depends upon the portion of the waveform to be limited or clipped. The practice of using crystal diodes as limiters is becoming more common in the new systems.



131.—Use of series diode limiter in Mark 25 Radar.

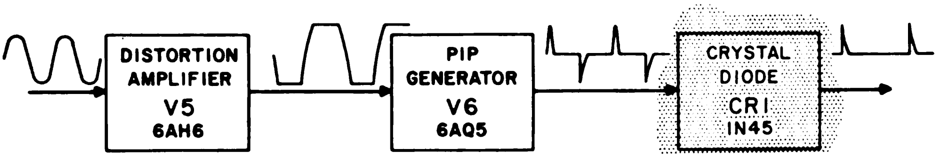
A series diode limiter is used in the synchronizing circuits of Radar Equipment Mark 25 Mod 3. The input to the limiter is a series of differentiated pulses produced in the plate circuit of the Reference Pip Generator, V2. When the input to the diode is positive, the diode will conduct and the input waveform is reproduced across R9. When the input is negative, the diode will not conduct and no voltage will be developed across R9. The series diode limiter, V3A, clips the negative pulses. The positive pulses in the output are used as triggers in the following synchronizing circuits.



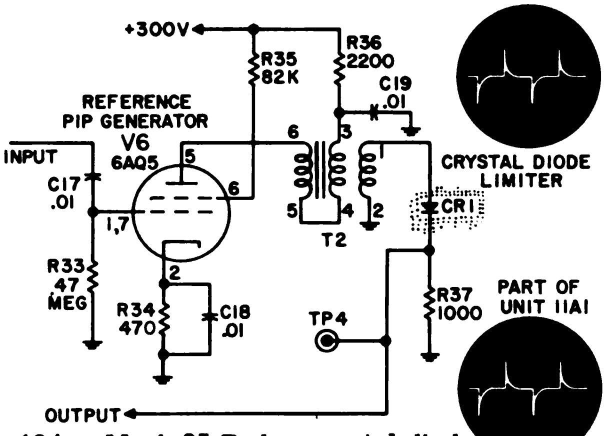
132.—Mark 25 Radar series diode limiter.

Applications—Diode Limiters (Continued)

On this page is given an application of a crystal diode used as a limiter. This circuit is also found in the Mark 25 Mod 3. It is almost identical to the circuit given on the previous page. The only difference is that a crystal is used in place of the tube.



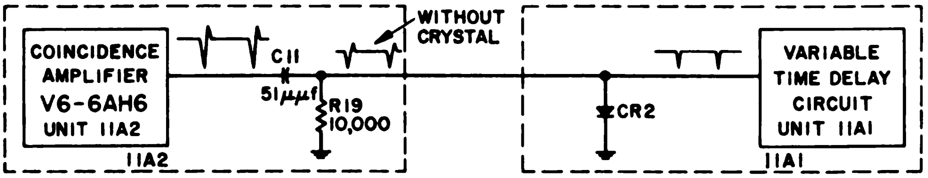
133.—Use of crystal diode limiter in Mark 25 Radar.



134.—Mark 25 Radar crystal diode limiter.

The crystal, CR1, functions as a series diode limiter to limit the negative peaks so that only the positive peaks appear in the output waveform. The remaining positive pulses are used as triggers in the following circuits. Compare this circuit with the one on the previous page.

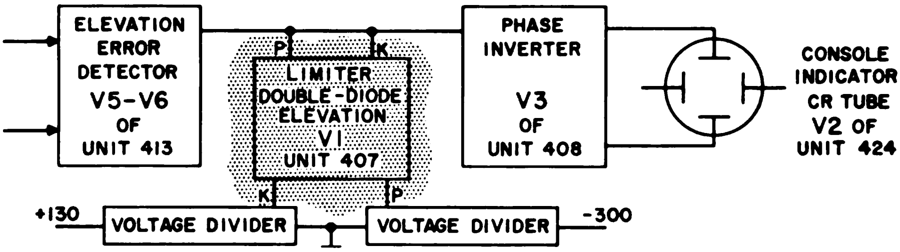
Another crystal diode is used as a limiter in the ranging circuits of the Mark 25 Radar. This crystal functions as a parallel limiter. Although its circuit is not identical to other limiter circuits that you have studied, you can readily see that its purpose is to clip the positive portion of the input signal to the variable time delay. The negative output of the coincidence amplifier is differentiated by the R-C circuit, consisting of C11 and R19. Both the negative and positive differentiated pulses would be available if a limiter were not used. The negative pulse is used to initiate the action of the variable time delay circuit. A positive pulse, if allowed to remain, would stop this action. CR2 clips the positive pulses and leaves the negative pulses to obtain definite triggering of the variable time delay circuit.



135.—Crystal diode as a parallel limiter.

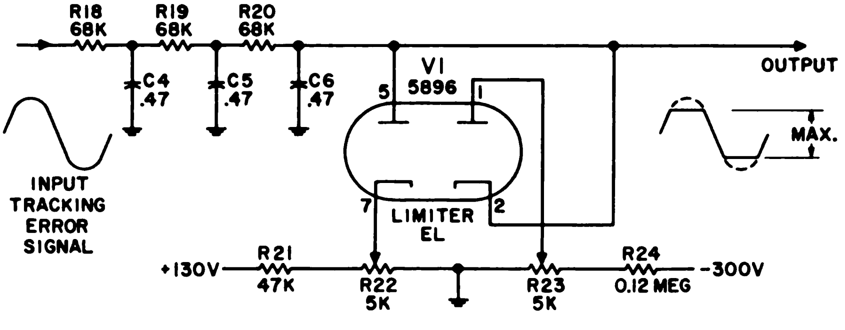
Applications—Diode Limiters (Continued)

The double-diode limiter is used in some fire control radar equipments. The one shown here will be found in the AN/SPG-50 in the circuits which provide tracking information to the director operator. This type of limiter is used so that large error signals will not drive the electron beam off the screen of the operator's cathode-ray indicator. Without this limiter the operator could not intelligently position the director on target since large signals could not be seen on the screen.


ELEVATION ERROR DETECTOR V5-V6 OF UNIT 413
P
K
LIMITER DOUBLE-DIODE ELEVATION V1 UNIT 407
K
P
PHASE INVERTER V3 OF UNIT 408
CONSOLE INDICATOR CR TUBE V2 OF UNIT 424
+130
VOLTAGE DIVIDER
VOLTAGE DIVIDER
-300

136.— Use of double-diode limiter in AN/SPG-50 Radar.

This limiter limits both the positive and negative peaks of the input signal. Maximum deflection of the electron beam is established by the predetermined values of R21-R22, and R23-R24. Control within these maximum limits is obtained by the use of potentiometers, R22 and R23. From simple calculations, it will be found that the maximum signal output in either direction will be 12 volts. That is, if R22 and R23 are both set for maximum voltage, then pin 7 of V1 will be +12 volts and pin 1 of V1 will be -12 volts. The output then will be a maximum of ±12 volts and any signals less than 12 volts will not be affected. The potentiometers must be set in accordance with the instructions given in the OP (Ordnance Pamphlet) for the equipment concerned. Maladjustment of the circuit will reduce the sensitivity of the electron beam so that accurate tracking is not possible.



137.—AN/SPG-50 Radar double-diode limiter.

As previously stated, crystal diodes are used frequently in fire control radar equipments. In the circuit at the top of this page, two crystal diodes could have been utilized to perform the same function as the vacuum-tube diodes. In fact, crystal-type diodes will be found in the pointing information channel of the Mark 34 Radar to perform the identical function, as is indicated at the top of this page.

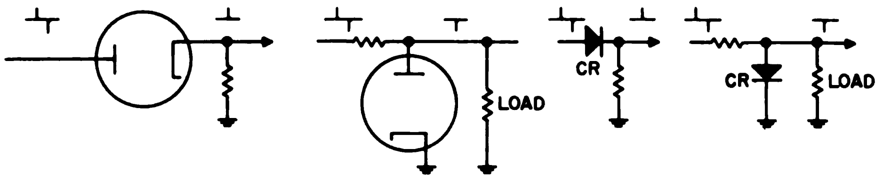
LIMITING CIRCUITS—DIODE TYPE

Review

This topic has presented diode limiting circuits in some detail. The principles of diode limiting action, as you have seen, are not complicated.

Listed below are some facts that you should have learned in this topic:

1. There are five kinds of diode limiting circuits.
   a. Series diode - positive limiter.
   b. Series diode - negative limiter.
   c. Parallel diode - positive limiter.
   d. Parallel diode - negative limiter.
   e. Double-diode limiter - limits both peaks.
2. Diode limiters are essentially shaping circuits.
3. They may be used to limit or clip either the negative or the positive portion of a waveform.
4. Double-diode limiting may be used to limit both the positive and negative peaks of an applied waveform.
5. Diode limiters may be used to limit a signal to a certain voltage level by means of a biasing voltage.
6. In series diode limiters, the output is the voltage drop across the resistor.
7. In parallel diode limiters, the output is the ratio of voltage dropped across the load resistor as compared to the series resistor.
8. Germanium crystal diodes are being more frequently used in radar circuits.
9. Crystal diode limiters are reliable units that require no special socket or excitation voltage and occupy a minimum of space.
10. They perform limiting action in the same manner as vacuum tube limiters.
11. All limiters function as they do because they offer high resistance to current flow in one direction and low resistance to current flow in the other direction.



SERIES LIMITER | PARALLEL LIMITER | SERIES LIMITER | PARALLEL LIMITER

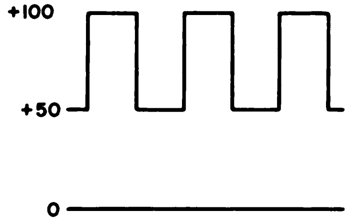
138.— Diode limiters— review diagram.

TOPIC 7: CLAMPING CIRCUITS

General Purposes

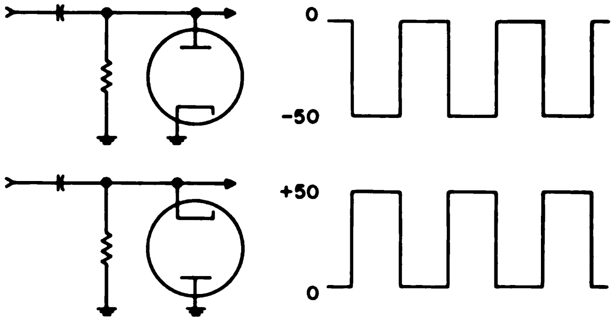
The next circuit that you are going to learn about is the clamper, or d-c restorer. A clamping circuit is one which shifts a waveshape so that it is all above or all below a certain voltage—often zero. It is called a clamping circuit because it clamps the top or bottom of a complete voltage waveshape at a certain voltage, which may be zero, any positive voltage, or negative voltage, depending upon the requirements of the circuit.

If you have a square wave taken directly from the plate of an amplifier tube.....



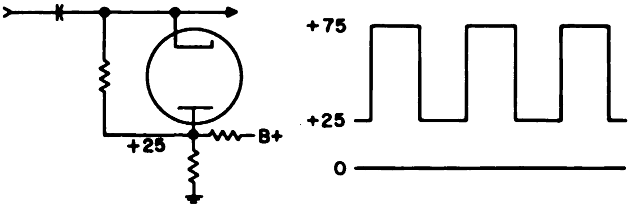
139.— Square-wave input to clamping circuit.

.....and put it into a clamping circuit, you can get out any of the following waves. A clamping circuit consists basically of a resistor, a capacitor, and a diode. The diode may be either a vacuum tube or a crystal. You will note that the amplitude of the waveform has not been changed, but the operating level has been shifted relative to zero voltage.



140.— Clamping circuit outputs.

When the top or bottom of the wave is to be clamped to a voltage above or below ground, a source of bias voltage is also necessary.



141.—Use of bias voltage in a clamping circuit.

General Purposes (Continued)

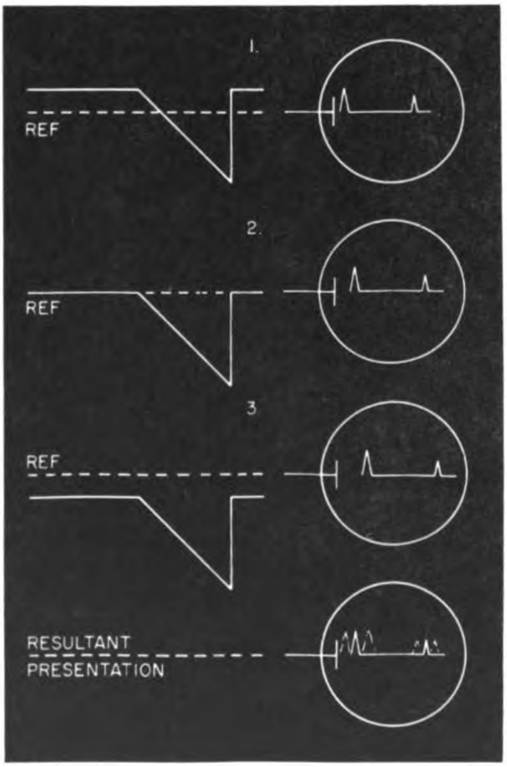
Although there are various applications for clamping circuits, they are usually associated with the sweep circuits in radar indicators. In a radar indicator, the sawtooth sweep generator may not produce sawtooth waves that start at the same voltage level. When this happens, the sweep trace may not begin each sweep at exactly the same point on the screen. It may be a little to the right or a little to the left of the desired beginning point. The result of this is a picture that "jitters" from side to side at a high frequency, causing blur or apparent poor focus.

142.—'Scope picture without clamping.

143.—'Scope picture with clamping.

In the diagrams, the sweep voltage applied to the radar indicator is not clamped. This permits the sweep voltage to rise from a slightly different level each time. In #1, the sweep voltage starts at a higher value than is desired and the sweep starts from the extreme left of the indicator. In #2, the sweep voltage rises from the normal desired level and the sweep starts at the desired point on the indicator. In #3, the sweep voltage starts at a lower level than is desired and the sweep appears further to the right.

Since these sweeps occur at the PRF of the radar, a continuous shifting of the starting level of the sweep voltage will produce a "jitter" effect on the screen. To eliminate this is the primary purpose of clampers; they insure that the sweep voltage will always start at the same reference level.

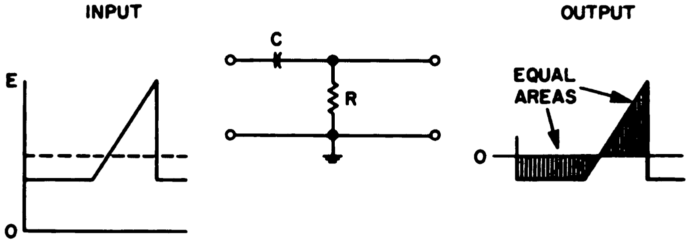


144.— Effect of changes in sweep voltage starting levels on 'scope presentation.

CLAMPING CIRCUITS

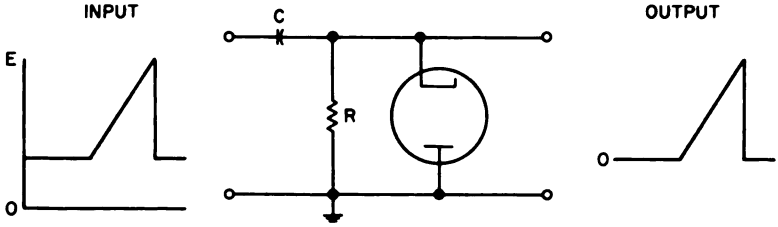
The Diode Clamper

You have seen the necessity for each successive sweep starting at the same spot on the face of the radar indicator tube. To see how this is accomplished, first consider what happens to the sweep voltage when it is fed through the ordinary R-C coupling circuit.



145. — R-C coupling circuit.

After a few cycles of sweep voltage are fed through the coupling circuit, the capacitor, C, is charged up to the average d-c value of the input. This means that the output varies above and below the zero level so that the areas above and below the zero level are equal.



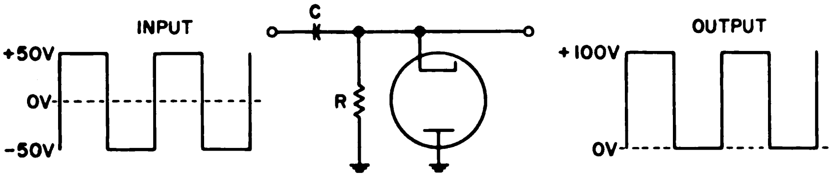
146. —Effect of a diode in R-C coupling circuit.

Now, if a diode is connected across the resistor as shown, the circuit becomes a diode clamper. The presence of the diode prevents the capacitor from charging to the average value, as it did in the case of the coupling circuit. The capacitor can charge up to the value at which the sweep begins, but the extra amount of charge it picks up during the sweep is quickly offset by conduction of the diode causing the capacitor to discharge when the sweep is over. By making the value of R very large, the amount of charge that the capacitor gains during the sweep voltage is kept small enough to have little effect on the waveform. This means that the output sweep from the diode clamper starts at zero.

CLAMPING CIRCUITS

The Positive Diode Clamper

An unbiased positive diode clamper reproduces the entire magnitude of the input waveform, with the output varying from zero voltage to some positive voltage.



147.— Positive diode clamper.

In this discussion, it will be considered that the circuit has been in operation for some time. If you wish to review circuit action at the time it is energized, you may refer to page 79 of topic 5.

In the positive clamper circuit shown above, note that the input varies from -50 volts to +50 volts, while the output voltage varies from zero to +100 volts. Both the input and the output change 100 volts. However, the output does not drop below zero.

Consider the positive-going portion of the square wave starting at -50 volts and rising to +50 volts. The capacitor must charge, and its charge path is across the resistance, R. Thus, the output terminal must rise from its zero level up to +100 volts. When the square-wave input commences its negative swing (+50 to -50), the capacitor must discharge. At the initial instant it starts to discharge across the resistor, the cathode of the diode becomes negative a slight amount relative to its plate and the diode conducts. This provides a fast discharge path for the capacitor and effectively connects the output terminal to ground during the discharge cycle.

It can be seen from the foregoing that the output terminal can go negative only a very slight amount since the diode conducts the instant the capacitor starts to discharge. However, the output terminal will go positive an amount equal to the magnitude of the input signal.

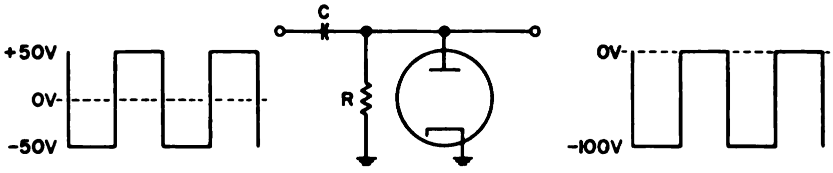
The Negative Diode Clamper

The unbiased negative diode clamper performs in the same manner as the positive diode clamper. There are two differences. One is that the connections to the diode are reversed. The other is that the output waveform will vary from zero to some negative voltage.

Circuit operation of the negative diode clamper can be analyzed in the same manner as that of the positive clamper, previously discussed.

The Negative Diode Clamper (Continued)

Consider the negative-going portion of the square wave starting at +50 volts and dropping to -50 volts. The capacitor must discharge across the resistance, R. Thus, the output terminal must drop from zero to a value of -100 volts. When the square-wave input starts to rise, the plate of the diode becomes positive and provides the capacitor with a short charge path, and the output terminal is effectively tied to ground. Thus, it can be seen that the output varies an amount equal to the input, but it is negative with respect to ground.

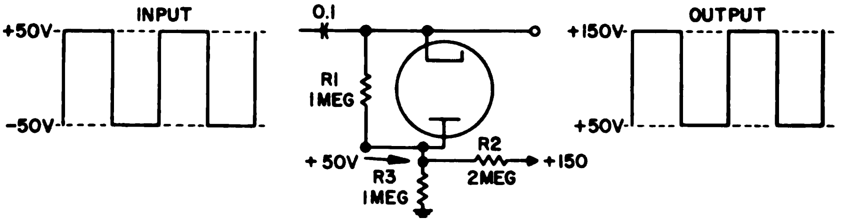


148.—Negative diode clamper.

The Biased Clamper

When it is desired to clamp a waveform to some value other than ground, a voltage source is connected into the circuit as a reference level. This replaces ground as the reference, and is referred to as the bias. In the circuit shown, a bias voltage of 50 volts is provided by R2 and R3. The capacitor then must charge to +50 volts and the output terminal will also be at +50 volts.

When the input signal rises from -50 volts to +50 volts, the output must change an amount equal to the 100-volt change. It does this across the shunt resistor, R1. The output terminal then has risen from its normal +50 volts to +150 volts. When the input waveform falls from +50 to -50, the capacitor will charge. At this time, the diode conducts, charging the capacitor to the value of the bias voltage. The output has now dropped from +150 to +50. Therefore, in the positive biased clamper, the input waveform is reproduced in the output, with all of it positive relative to the reference level.



149.—Positive diode clamper with positive bias.

In the diagram above, if the diode connections were reversed and a negative bias voltage used, the input waveform would be reproduced in the output, but all of it would appear negative relative to the negative bias voltage.

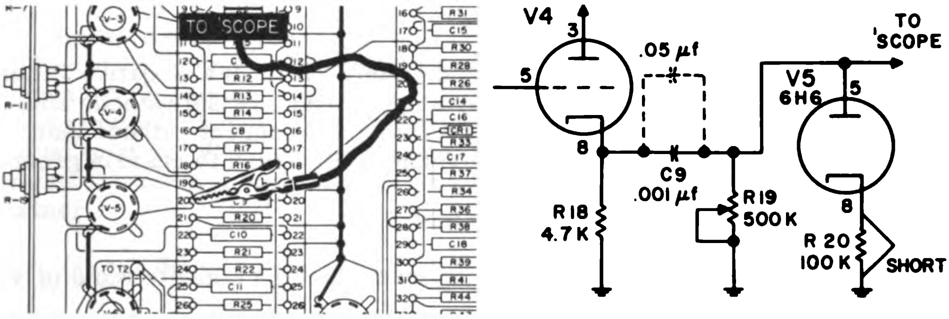
CLAMPING CIRCUITS

Experiment—Test Setup

In this experiment, you will see how a clamping circuit operates to control the output waveforms so that the voltage excursions are either all above or all below a zero voltage reference level. You will convert the limiter stage V5 into a negative clamping circuit. You will use the output of the cathode follower as the input to the clamper.

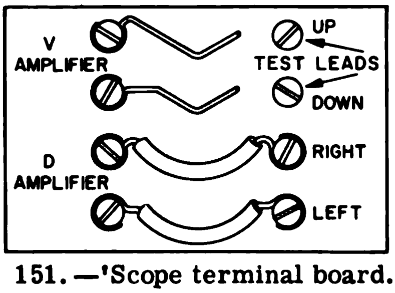
You will need a 'scope, multimeter, and a .05-mfd, 600-volt tubular capacitor.

To convert V5 to a negative clamper, connect a jumper from pin 8 of V5 to chassis ground. Connect the .05-mfd capacitor in parallel with C9 and set R19 to maximum resistance to increase the time constant of the input circuit to the clamper. This will prevent differentiation of the square wave.



150.—Clamping circuit—test setup.

In order to observe clamping action, your 'scope presentation must be able to show the position of the waveform relative to a zero reference level. This can be achieved by feeding the signal directly to the deflection plates rather than to the deflection amplifier. If the signal is fed through the deflection amplifier, the capacitive coupling circuits will remove the d-c component of the waveform. If the signal is fed directly to the deflection plates, the entire waveform will be displaced from the reference level. All 'scopes have provisions for applying a signal directly to the deflection plates. Usually there is a terminal board at the back of the 'scope with a series of eight terminals divided into two sets of four each. One set of terminals provides connections to the outputs of the deflection amplifiers. The other set provides connections to the deflection plates of the cathode-ray tube. In normal 'scope operation, jumpers will connect the output of each amplifier to its corresponding deflection plate.



151.—'Scope terminal board.

Remove the jumpers connecting the vertical amplifiers to the vertical deflection plates and connect the test leads to the terminals connected to the deflection plates of the 'scope tube. In the experiment to follow, connect one of the test leads to the chassis and the other to the signal source. Connect the 'scope leads so that the waveforms match those shown in the illustrations.

CLAMPING CIRCUITS

Experiment—Negative Diode Clamper

Step 1. Determine the zero input reference line. Ground the 'scope probes and note the position of the trace against the grid lines.

Step 2. Connect test leads. One lead is connected to ground and the other to pin 5 of V5.

Step 3. Observe the waveform without clamping, by removing V5. Note that the waveform varies about the zero reference level. On some 'scopes it may not be possible to bring the picture into focus.

Step 4. Observe the waveform with clamping. Replace V5 and note that the waveform shifts downward so that its positive peaks coincide with the zero reference line. (If the image shifts upward, reverse the 'scope connections.) It will be noted that the excursions of the output waveform are all below the zero reference level.

Experiment—Positive Diode Clamper

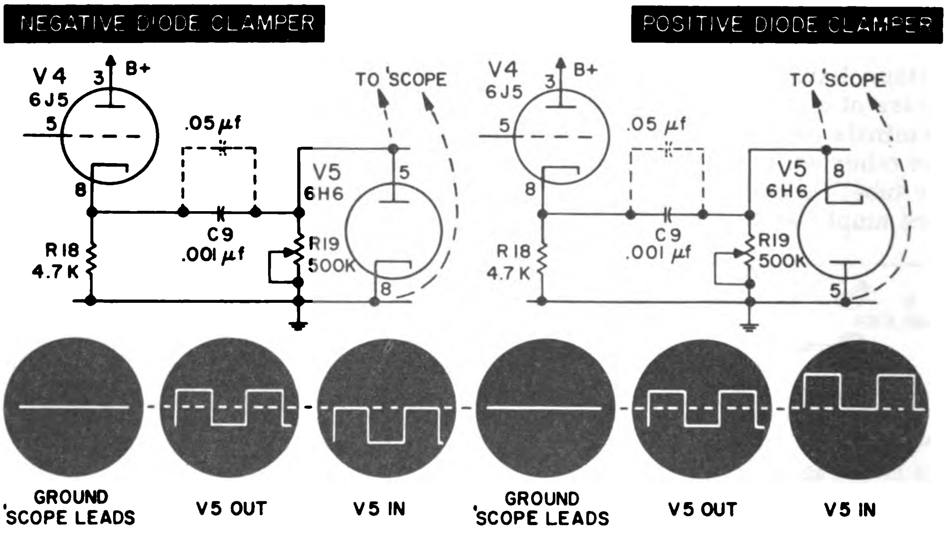
Step 1. Secure power to the chassis and modify V5 from a Negative Diode Clamper to a Positive Diode Clamper. Remove the cathode and plate leads of V5 from terminal board and connect cathode lead to junction of C9 and R19. Then connect plate lead to chassis ground.

Step 2. Establish zero reference line as before.

Step 3. Connect test leads—one lead to ground and the other to pin 8 of V5.

Step 4. To observe waveforms without clamping, remove V5. Note that the waveform varies about the zero reference line.

Step 5. Observe waveforms with clamping. Replace V5 and note that the waveform shifts upward so that its negative peaks coincide with the zero reference line.



152. — Diode clamper— checking clamping effects.

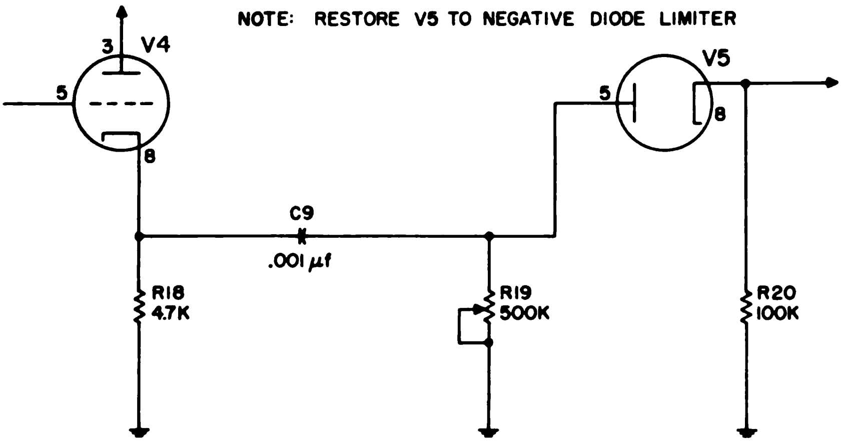
Experiment—Trouble Shooting

Trouble shooting the diode clamper is comparatively simple. Because a clamper inserts or restores a d-c level to an a-c signal, a d-c voltage will exist across the output of a clamper. Therefore, one check of normal clamper operation is to measure the d-c voltage level across the clamper. A positive clamper will give a positive d-c voltage reading; a negative clamper will give a negative d-c voltage reading.

A 'scope will not always indicate trouble in a clamper circuit. For example, if the clamper tube is not emitting, the 'scope will still indicate the presence of a signal across the clamper even though a d-c level has not been restored to the signal. You observed in the previous experiment that with V5 out of the circuit, the waveform was present without clamping action. The 'scope will indicate loss of clamping action if the signal is connected directly to the deflection plates. However, with V5 not emitting, a voltmeter can be used to detect the trouble. It would read zero volts across the clamper tube.

You have seen in your experiments on diode clampers what happens if the diode does not conduct (V5 out). Listed below are other casualties you may encounter. Insert each of these casualties, one at a time, in the positive diode clamper circuit. Then observe the effects on the output with a 'scope and voltmeter. When you have done this, you will have a record that will be useful when you start trouble shooting casualties inserted by your partner.

1. Shorted shunt resistor (R19).
2. Shorted coupling capacitor (C9).
3. Open shunt resistor (R19).
4. Open coupling capacitor (C9 and its shunt capacitor).

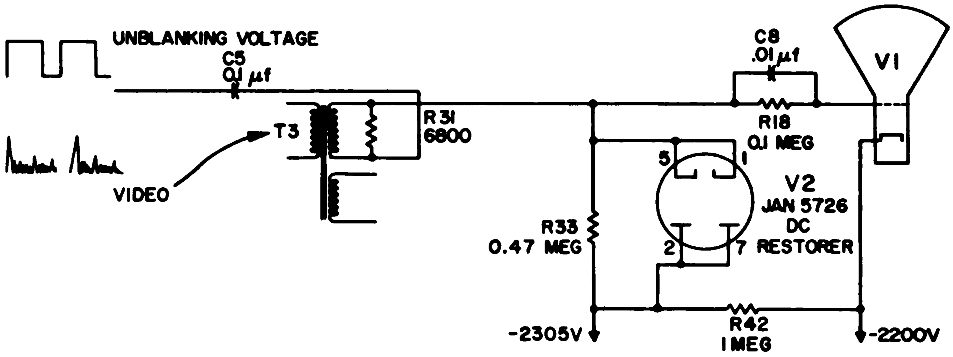


153.—Diode clamper—trouble shooting.

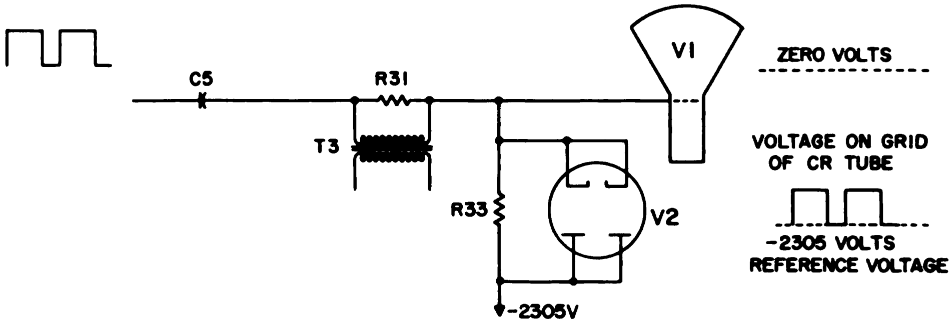
Applications

An example of a positive diode clamper with negative bias is found in the indicator circuits of Radar Equipment Mark 25 Mod 3.

Normally, the indicators are biased into cut-off by establishing the grid at -105 volts relative to the cathode. In this condition, no electrons travel from the cathode to the screen of the CRO (V1). The 'scope is unblanked at the desired time by an unblanking voltage which is synchronized with the sweep voltages applied to the deflection plates. The purpose of the clamper circuit is to insure that the grid will return to the desired bias level during the trace return time ('scope blanked). Since the unblank voltage is positive, the grid will be driven in a positive direction. This permits electrons to reach the screen during sweep time. At the end of the sweep, the unblanking voltage terminates. This means that the capacitor (C5) must discharge any of the charge that it accumulated during charge time, and the diode clamper provides a fast discharge path. The control grid of the CRO (V1) will be clamped at the normal -105 volt bias (-2305 volts).



154.—Clamper (dc restorer) in Mark 25 Radar.



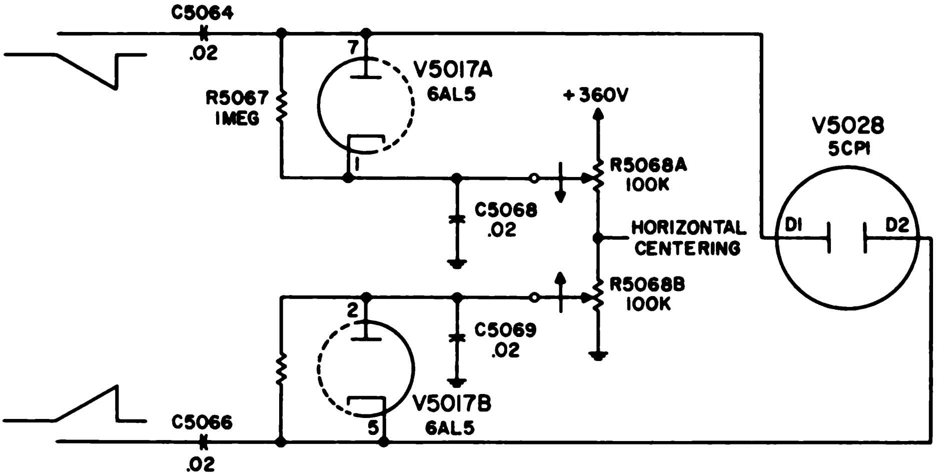
155.—Simplified circuit of clamper.

From the above, it can be seen that the unblanking voltage will be clamped at a level of -2305 volts; that is, it will only vary from -2305 in a positive direction.

The purpose of T3 in this circuit is for the insertion of positive video pulses on the grid of V1.

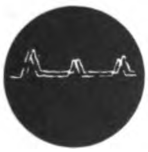
Applications (Continued)

The next example of the use of clamping circuits in the Indicating Systems of fire control radars is from the Mark 35 Radar. In this application, the negative clamper with positive bias and a positive clamper with positive bias are used to insure that each successive sweep on the indicator tube, V5028, will start at the same point.

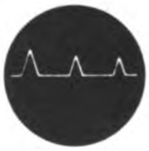


156.— Clamper in Mark 35 Radar.

The voltage at the left deflection plate of the indicator tube is clamped at the voltage on the arm of R5068A. The voltage swing on this plate is in a negative direction from the positive voltage reference. At the end of the sweep, the voltage on D1 will return to the reference voltage due to action of negative clamper V5017A. The voltage on the right deflection plate is clamped at a lower positive voltage reference level, the voltage on the arm of R5068B. The voltage swing on D2 is in a positive direction from the reference level. At the end of the sweep, the voltage on D2 returns to the reference level due to action of positive clamper V5017B. At the beginning of each sweep, the difference in the voltages of D1 and D2 will be a fixed amount. This difference will be the voltage between the arms of R5068A and B. This fixed voltage difference insures that the sweep trace will always start at the same spot on the face of the indicator tube.



157.—'Scope picture without clamping.



158.—'Scope picture with clamping.

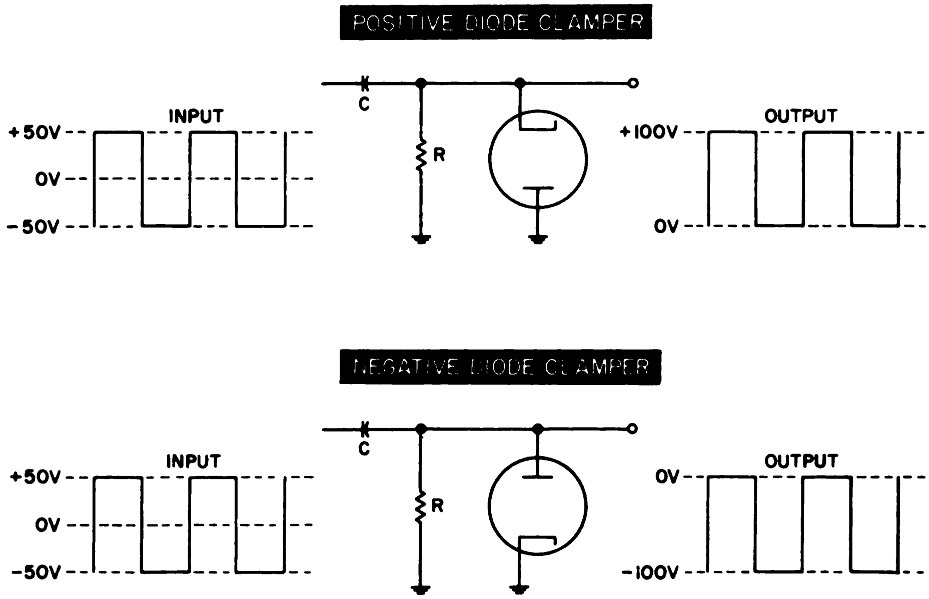
CLAMPING CIRCUITS

Review

This topic has discussed another use of diodes, both vacuum and crystal types.

Listed below are some of the facts you should have learned in this topic:

1. The output waveform retains all of the characteristics of the input.
2. The output waveform is shifted above or below a certain reference, depending upon the circuit arrangement.
3. There are several types of diode clamper circuits:
   (a) Positive clamper
   (b) Negative clamper
   (c) Positive clamper with positive bias
   (d) Negative clamper with negative bias
   (e) Positive clamper with negative bias
   (f) Negative clamper with positive bias.
4. The positive clamper shifts all of the waveform in a positive direction from the reference level.
5. The negative clamper shifts all of the waveform in a negative direction from the reference level.
6. A common application of clampers is in the radar sweep circuits to prevent "jitter" of the sweeps, with resultant blurring of target echoes.



159.— Diode clampers-review diagram.

Notes

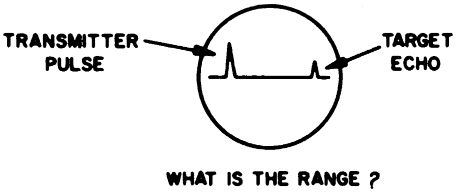
TOPIC 8: BLOCKING OSCILLATORS

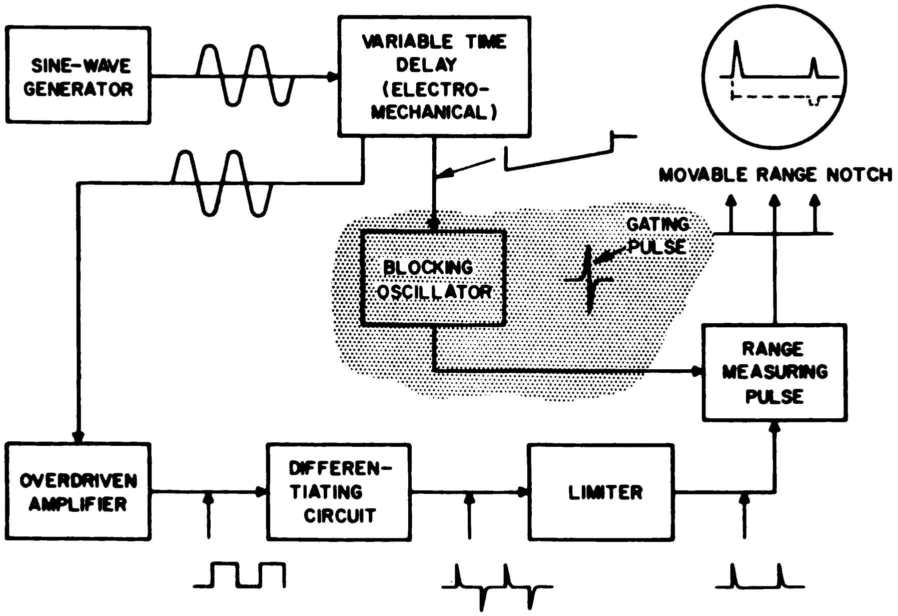
General Purposes

Another circuit frequently encountered in fire control radars is the blocking oscillator. It is classified as a generating circuit, since it actually generates a new waveform instead of reshaping one that is fed into it. Its most important uses are to generate gating pulses and triggers that require waveforms of a definite duration and that reoccur at a specific frequency.

The characteristic of blocking oscillators, that are used in fire control radars, is that they put out one cycle of oscillation followed by a period of no output. The single oscillation is of very short duration—only several microseconds or less—and the period of no signal output is much longer—usually several hundred microseconds.

In fire control radars, the most used function of blocking oscillators is to generate gating pulses. A series of blocking oscillators will be found in the synchronizing and ranging circuits of these radars. Their use in conjunction with timing pulses provides accurate delays.





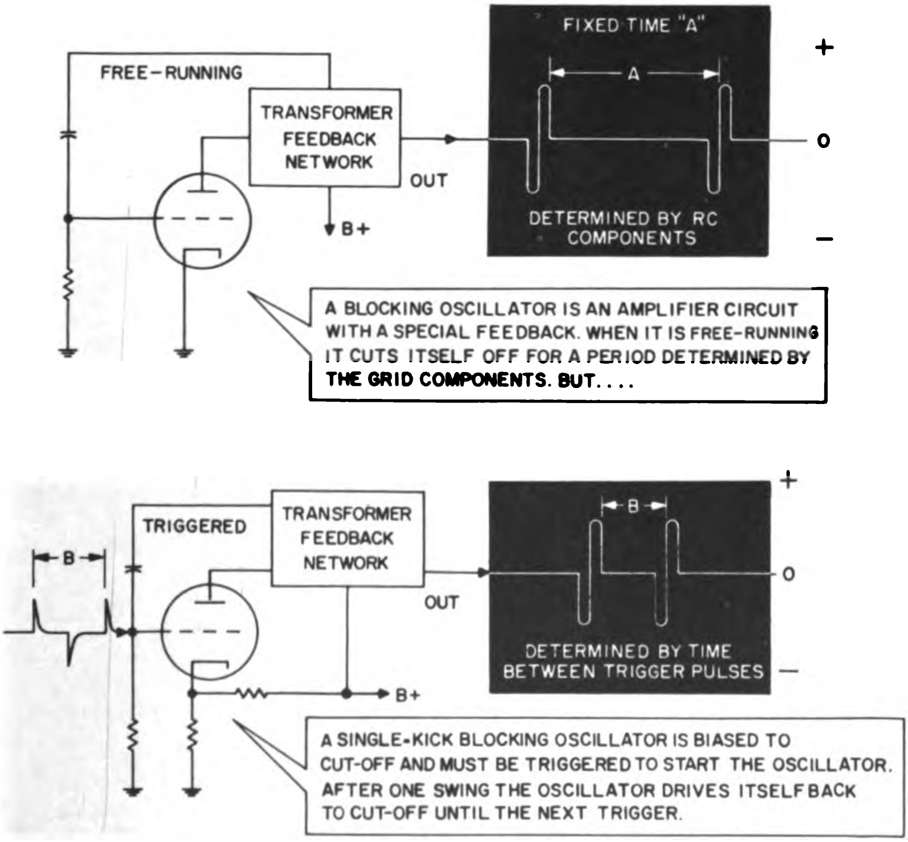
160. — The blocking oscillator.

BLOCKING OSCILLATORS

How the Blocking Oscillator Works

Basically, there are two types of blocking oscillators. One type is free-running, which means it will go through a cycle of operation without a signal applied to it. The frequency of this type of blocking oscillator is established by the values of the circuit components.

The second type of blocking oscillator is the one which is encountered in fire control radar equipment. This type is the one which we will be concerned with in this topic. This blocking oscillator is biased into cut-off and will not operate unless a trigger pulse is applied. Since they oscillate for one cycle each time they are triggered, they are usually referred to as "single-kick" blocking oscillators. The duration of the operating cycle of a "single-kick" blocking oscillator is determined by the value of the circuit components. Its frequency is determined by the frequency of the trigger pulse.


FREE-RUNNING
TRANSFORMER FEEDBACK NETWORK
OUT
B+
FIXED TIME "A"
A
+
0
−
DETERMINED BY RC COMPONENTS
TRIGGERED
B
TRANSFORMER FEEDBACK NETWORK
OUT
B+
B
+
0
−
DETERMINED BY TIME BETWEEN TRIGGER PULSES

A BLOCKING OSCILLATOR IS AN AMPLIFIER CIRCUIT WITH A SPECIAL FEEDBACK. WHEN IT IS FREE-RUNNING IT CUTS ITSELF OFF FOR A PERIOD DETERMINED BY THE GRID COMPONENTS. BUT....

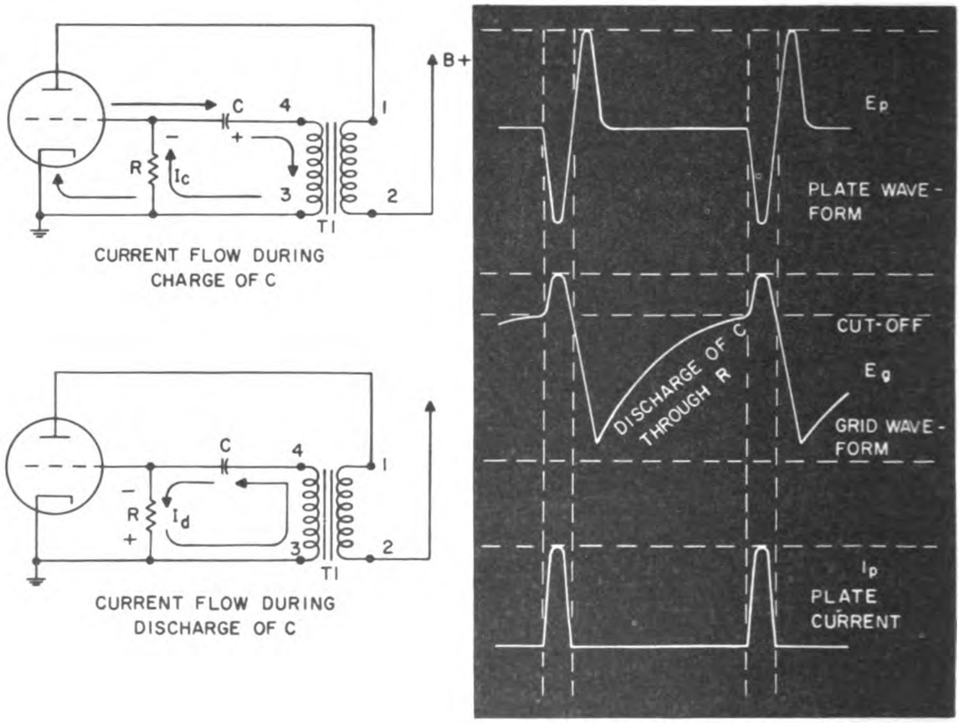
A SINGLE-KICK BLOCKING OSCILLATOR IS BIASED TO CUT-OFF AND MUST BE TRIGGERED TO START THE OSCILLATOR. AFTER ONE SWING THE OSCILLATOR DRIVES ITSELF BACK TO CUT-OFF UNTIL THE NEXT TRIGGER.

161.—Comparison of a free-running and triggered blocking oscillators.

How the Blocking Oscillator Works (Continued)

To learn the basic principles of the blocking oscillator, you will first study the free-running type.

There is no bias on the tube in the circuit below. When B+ is applied to the circuit, current will flow through the tube and the 1-2 winding of T1. This flow of current causes terminal 1 to become negative in relation to terminal 2 and produces a positive voltage at terminal 4. The capacitor must charge and, initially, some of the charge appears across the resistance. This action drives the grid positive with respect to the cathode, and the grid draws current, providing a short charge path for the capacitor. During this time, plate current is increasing and continues to increase until saturation current is reached. There will be no further increase in current through the 1-2 winding of the transformer. The rate of change in current through this winding has become zero and no voltage is produced across the 3-4 winding. The grid voltage drops and the capacitor starts to discharge through the resistance, driving the grid further in a negative direction. The negative-going grid voltage results in plate current decrease to cut-off, and the collapsing magnetic field drives terminal 1 sharply positive and terminal 4 sharply negative. The tube will remain cut off until the capacitor has discharged to the point that the control grid voltage rises above cut-off. When this point has been reached, the cycle will repeat itself. The time duration of the rise and fall of plate current is determined by the inductance and resistance of the transformer. The time between plate current cut-off and time that plate current begins to flow again is determined by the R-C time constant of the resistor and capacitor in the grid circuit and the cut-off voltage of the tube.

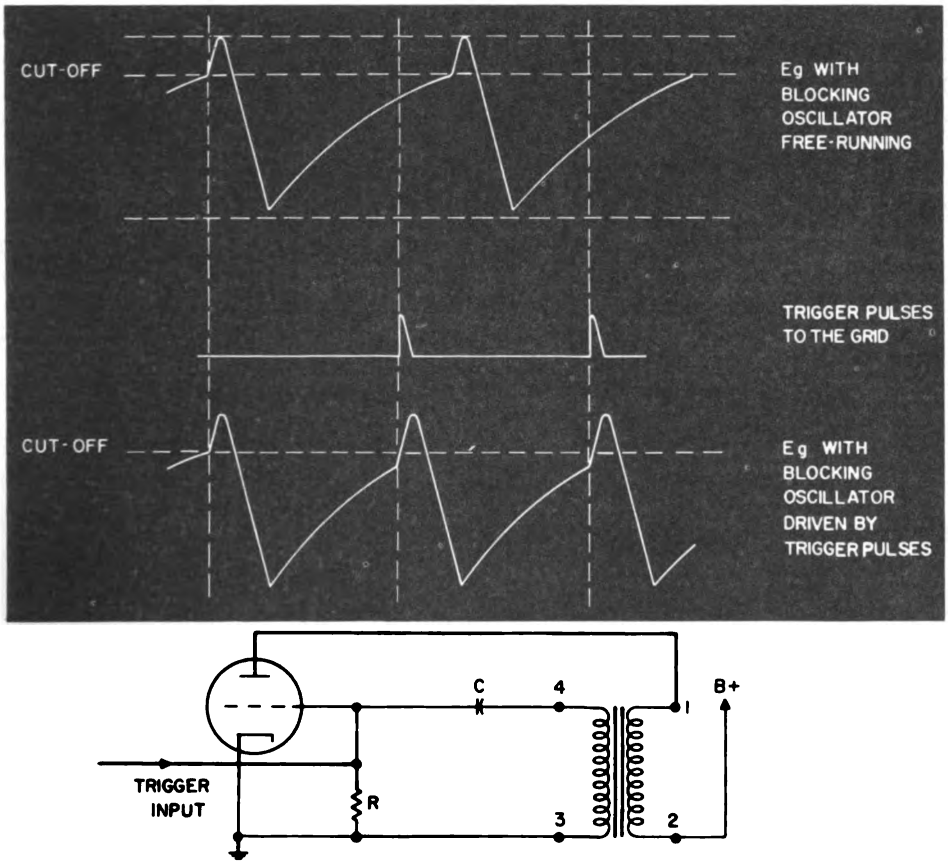


162. — Free-running blocking oscillator action.

How the Blocking Oscillator Works (Continued)

Now let us see what would happen in the circuit on the opposite page when a positive trigger is applied.

If, while the grid capacitor is discharging and the tube is cut off, a positive voltage trigger of sufficient amplitude to raise the grid above cut-off is applied, the tube will conduct and put out a cycle of voltage. It will then cut off until the next trigger is applied. In order for these triggers to drive the stage correctly, the time between them must be less than the cut-off time of the blocking oscillator when it is free-running.


CUT-OFF
Eg WITH BLOCKING OSCILLATOR FREE-RUNNING
TRIGGER PULSES TO THE GRID
CUT-OFF
Eg WITH BLOCKING OSCILLATOR DRIVEN BY TRIGGER PULSES
C
4
B+
1
TRIGGER INPUT
R
3
2

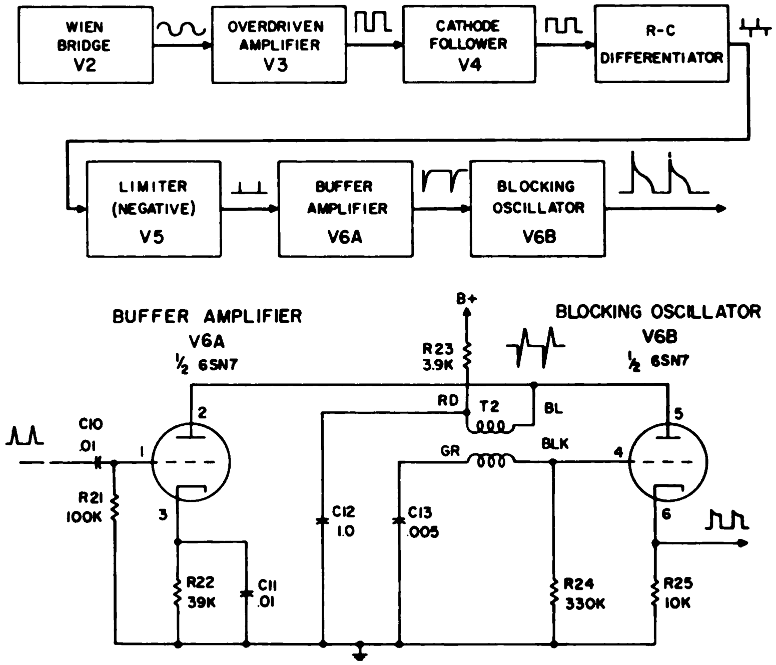
163.—Triggered blocking oscillator action.

In all blocking oscillators, saturation current (no further change) must be reached in some part of the circuit. This may be either in the tube or the transformer. In the preceding discussion, you will notice that the tube is indicated as reaching saturation. In practice, you will usually find that a magnetic core transformer is selected so that it will reach saturation before the tube. The advantage gained by the use of a saturable core transformer is that, in use, it is less liable to variation than a vacuum tube. This affords more stable operation of the circuits that use blocking oscillators.

How Your Blocking Oscillator Works

The blocking oscillator in the special circuits chassis is of the triggered type. It receives its trigger pulse from the preceding stage. The sine-wave output of the Wien bridge oscillator (V2) is shaped into a square wave by the overdriven amplifier (V3). The cathode follower (V4) couples the square wave to the differentiating circuit composed of C9 and R19. The differentiator shapes the square wave into positive and negative pulses. The negative pulses are limited by diode limiter (V5). The remaining positive pulses are inverted and amplified in buffer amplifier (V6A) and applied as triggers to blocking oscillator (V6B). The output waveform from the blocking oscillator will reoccur at the frequency of the Wien bridge oscillator.

To isolate the blocking oscillator from the negative diode limiter, it was necessary to install a buffer amplifier between the two stages. Without the buffer amplifier, the large negative voltage swing on the grid of the blocking oscillator would have been coupled to the cathode of the diode limiter and would have appeared as an additional pulse in the plate waveform of V5. The signal would have affected the previous stages. The buffer amplifier prevents distortion in the input waveform to the limiter.



164.—Blocking oscillator in special circuits chassis.

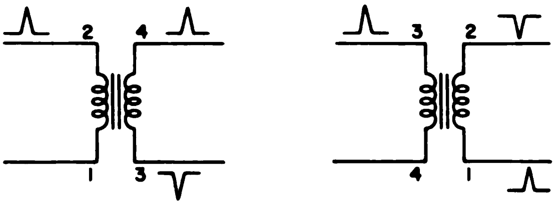
In the plate circuit of the blocking oscillator, you will encounter a decoupling circuit consisting of C12 and R23. This circuit is required due to excessive loading of the power supply when the blocking oscillator is operating. This loading effect is reduced enough so that the power supply (B+) does not vary greatly and, therefore, does not affect operation of other circuits in the chassis.

How Your Blocking Oscillator Works (Continued)

On the preceding pages, a basic free-running blocking oscillator circuit was discussed. You will find the same basic circuit in your chassis.

If the input from the Wien bridge oscillator is removed, you can determine, by signal tracing, that the blocking oscillator is operating. Since no signal is applied, it is called a free-running blocking oscillator. The circuit is now essentially the same as the basic blocking oscillator, discussed on the previous pages. Circuit components have been shifted, but their function in the circuit remains the same. The free-running frequency is determined by C13 and R24 and the characteristics of the tube (V6B).

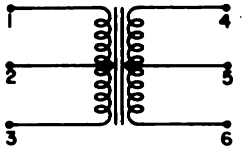
Most of the blocking oscillators you will encounter will be triggered blocking oscillators, of which there are many variations. Some of these variations will be in the placement of components, the triggering, and in the coupling of the output waveform to the next stage. The triggering pulse may be applied directly to the grid, through a separate transformer winding to the grid, or through the plate winding of the transformer to the grid. The output from the blocking oscillator may be taken from the plate, from the grid, from the cathode, or from a separate transformer winding. In your blocking oscillator, a negative trigger is inverted in T2 and applied as a positive trigger to the grid. The output waveform is taken across R25 in the cathode circuit.



165.—Transformer polarities.

In transformers used in blocking oscillators, it is necessary that the polarity of the windings is correct. You will note in the wiring of T2 that the green lead is connected to C13 and the black lead is connected to grid terminal 4 of V6. Although this wiring varies from the standard color coding, it was necessary in order to obtain operation of the blocking oscillator using this transformer. Terminal numbers on transformers provide a key to the polarity of the waveforms at the terminals. All of the even-numbered terminals will have the same polarity. All odd-numbered terminals will have the same polarity, but will be opposite in polarity to the even-numbered terminals. If terminal 4 is positive, then terminal 2 will be positive, and terminals 1 and 3 will be negative. This same rule applies when there are three or more windings of the transformer that are used.

NOTE: This numbering system for determining polarities of terminals does not apply to center-tapped transformers. This becomes obvious as you examine the numbers given to the terminals for this type of transformer.



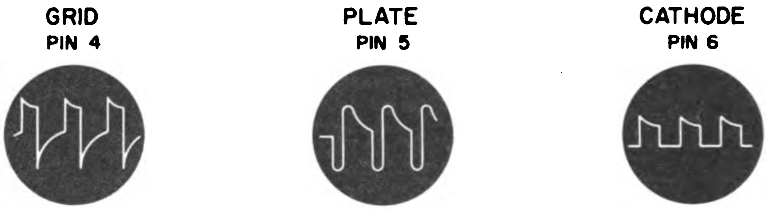
166.—Center-tapped transformer terminals.

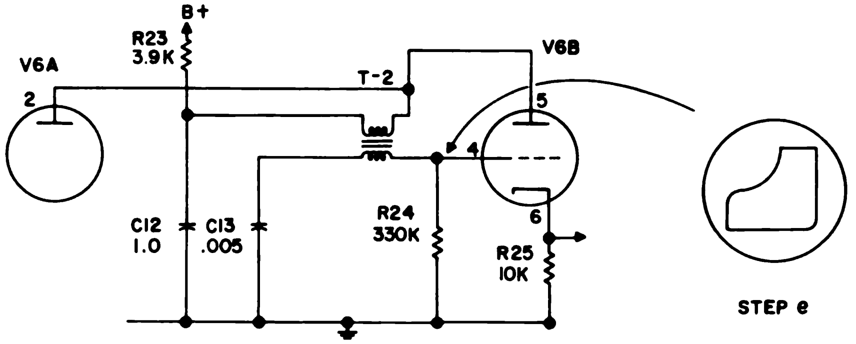
BLOCKING OSCILLATORS

Experiment—Free-Running Blocking Oscillator

You are now going to check waveforms and determine the free-running frequency of the blocking oscillator in your chassis.

1. Disable the input trigger to buffer amplifier and blocking oscillator circuit. This can be done by turning R19 clockwise to zero resistance.
2. Insert the blocking oscillator tube V6 (6SN7).
3. Signal-trace with oscilloscope. Observe waveforms at grid, plate, and cathode of V6B (pins 4-5-6).





167. — Free-running blocking oscillator— checking frequency.

4. Check free-running frequency of the blocking oscillator.
   - a. Connect output of signal generator to Horizontal input (X-axis) of 'scope and set coarse frequency control to Amp. in (Horiz. Amp).
   - b. Connect ground lead of signal generator to special circuits chassis.
   - c. Connect 'scope ground lead to special circuits chassis.
   - d. Connect Vertical Amp. (Y-axis) to grid pin 4 of V6.
   - e. Energize all equipment and adjust FREQUENCY control on the signal generator to obtain one stationary "closed-loop" pattern on the oscilloscope. (It may be difficult to stop rotation of the pattern, so a close approximation of the frequency will be obtained with the pattern rotating very slowly.) Read and record the frequency that is indicated on the signal generator.

Experiment—Triggered Blocking Oscillator

In this experiment, you will use all of the stages ahead of the blocking oscillator to obtain the trigger pulse. You will observe the waveforms at the grid, plate, and cathode of the blocking oscillator. You will measure the frequency of the blocking oscillator and note that it is the same as that of the Wien bridge oscillator. You also will note that the frequency of the triggered blocking oscillator is higher than that of the free-running blocking oscillator.

1. Adjust R4 and R7 for a good sine-wave output from the Wien bridge oscillator. Use the 'scope to observe the waveform at plate pin 5 of V2.

2. Observe the waveform at cathode pin 8 of V4 for a good square wave. If necessary, adjust R11.

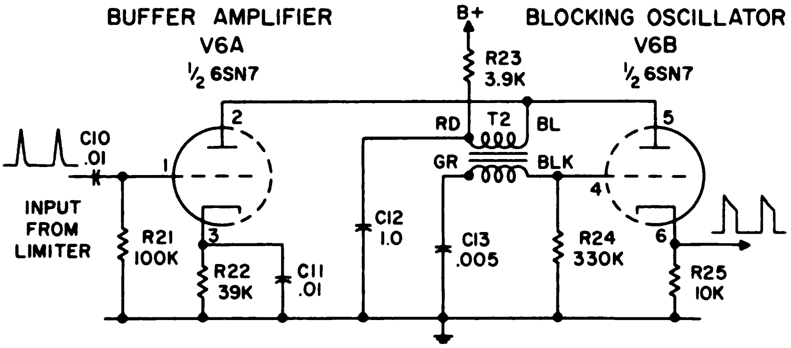
3. Observe the waveform at cathode pin 8 of V5. If necessary, adjust R19 for good differentiation of the positive pulse.

4. Use the 'scope and observe the waveforms at the grid, plate, and cathode of the blocking oscillator (pins 4-5-6 of V6).

5. Check the output frequency of the triggered blocking oscillator by repeating steps a, b, c, d, and e of #4 in the previous experiment.

6. Check the output frequency of the Wien bridge oscillator.

   a. Repeat steps a, b, and c of #4 in the previous experiment.
   b. Connect 'scope probe to plate pin 5 of V2 and observe that a single stationary waveform is visible.



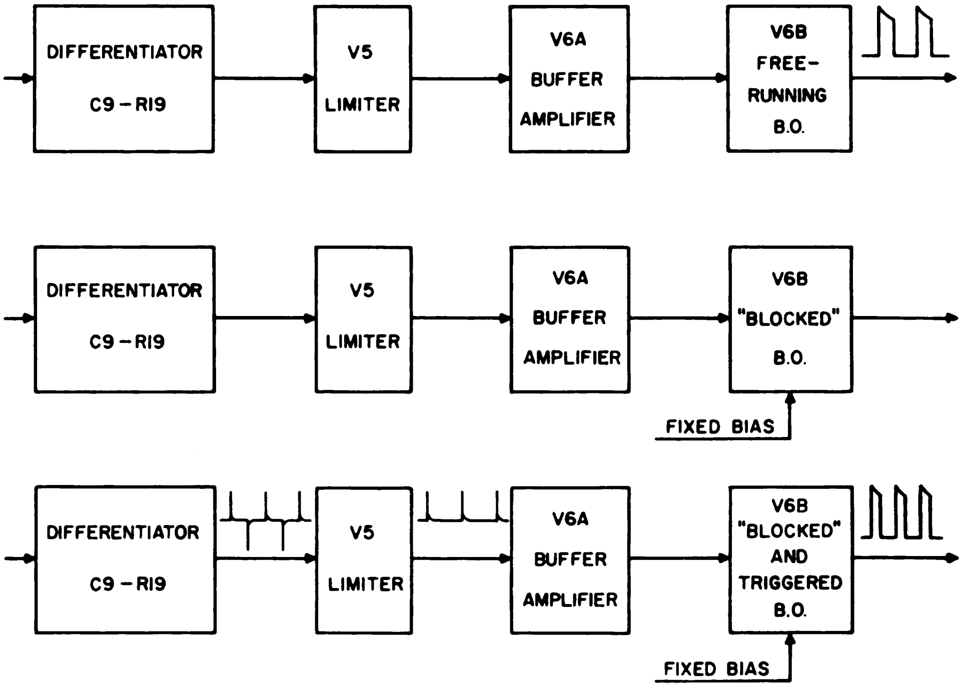
168.— Trigger blocking oscillator—checking frequency.

7. You have observed that the output frequency of the blocking oscillator is the same as the frequency of the Wien bridge oscillator. This is true since the Wien bridge oscillator is the source of the signal used to trigger the blocking oscillator. Note that the frequency of the triggered blocking oscillator is higher than that of the free-running blocking oscillator.

Experiment—"BLOCKED" Blocking Oscillator

As you have already seen, the free-running blocking oscillator can be triggered by some external signal. The requirement for frequency stability in this case is that the trigger frequency must be higher than the free-running frequency.

In fire control radar equipments, nearly all blocking oscillators are biased into cut-off and require a trigger of sufficient amplitude to bring them into operation. They then produce one output pulse, and the fixed bias holds the blocking oscillator cut off until the next trigger is applied. Since a fixed bias is used to hold the blocking oscillator in cut-off after one operating cycle, it is permissible to have its free-running frequency higher than the trigger frequency. This is sometimes desirable so that a very sharp output pulse can be obtained for use in gating other signals. This feature is especially desirable in circuits that are used to develop time synchronizing signals.

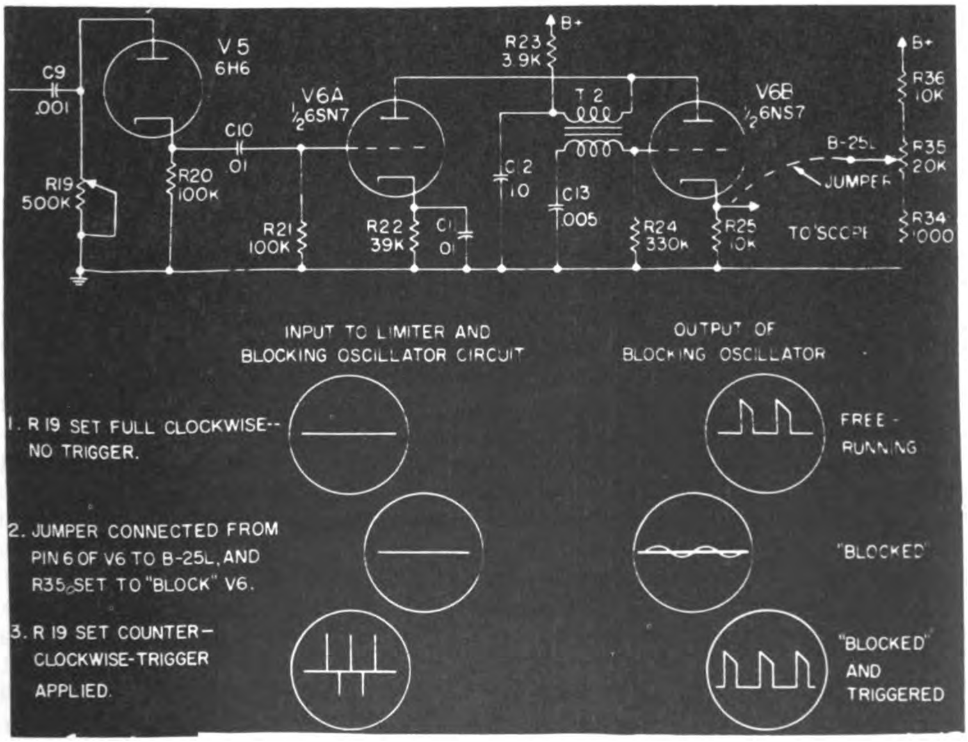


169.—Output pulse from "blocked" and triggered blocking oscillator.

BLOCKING OSCILLATORS

Experiment—"BLOCKED" Blocking Oscillator (Continued)

1. Remove trigger to blocking oscillator—turn R19 full clockwise.
2. With 'scope probe on cathode pin 6 of V6, determine that the blocking oscillator is operating.
3. De-energize the chassis.
4. Bias blocking oscillator into cut-off. Connect jumper from cathode pin 6 of V6 to arm of R35 (terminal board "B," B-25L). Turn R35 full counterclockwise.
5. Energize the chassis.
6. Set vertical gain of 'scope to high value and adjust R35 to point where the blocking oscillator stops operating. With voltmeter, determine voltage on pin 6 of V6.
7. Trigger the blocking oscillator—turn R19 counterclockwise until a good waveform is observed on the cathode.
8. NOTE: a. With no trigger, the blocking oscillator is free-running.
   b. With bias voltage on the cathode, the blocking oscillator is cut off ("blocked").
   c. With bias voltage and a trigger, the blocking oscillator is unblocked, and operates at the trigger frequency which is determined by the Wien bridge oscillator.


C9
.001
V5
6H6
R19
500K
R20
100K
C10
.01
V6A
½6SN7
R21
100K
R22
39K
C11
.01
B+
R23
3.9K
T2
C12
10
C13
.005
R24
330K
R25
10K
V6B
½6NS7
B+
R36
10K
B-25L
R35
20K
JUMPER
TO SCOPE
R34
1000
INPUT TO LIMITER AND BLOCKING OSCILLATOR CIRCUIT
OUTPUT OF BLOCKING OSCILLATOR
1. R 19 SET FULL CLOCKWISE-- NO TRIGGER.
FREE-RUNNING
2. JUMPER CONNECTED FROM PIN 6 OF V6 TO B-25L, AND R35 SET TO "BLOCK" V6.
"BLOCKED"
3. R 19 SET COUNTER-CLOCKWISE-TRIGGER APPLIED.
"BLOCKED" AND TRIGGERED

170. —Blocking oscillator—checking outputs.

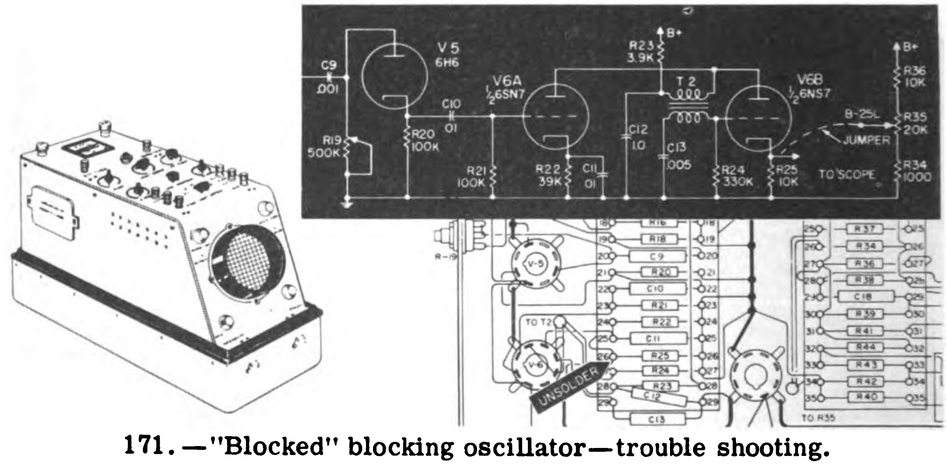
BLOCKING OSCILLATORS

Experiment—Trouble Shooting the "BLOCKED" Blocking Oscillator

Trouble shooting the blocking oscillator requires the same procedures as for trouble shooting any other circuit. A 'scope and a volt-ohmmeter will be necessary to locate some of the casualties in this circuit. The 'scope is an excellent test instrument for locating trouble in the blocking oscillator. A casualty in the circuit will be apparent in the output waveform. Distortion indicates that some circuit component is defective. No output indicates loss of the input trigger or failure of some circuit component. As in other circuits, the most frequent casualty is the tube. If the casualty is not the tube, voltage and resistance measurements are necessary to locate the defective component. Loss of bias will permit the blocking oscillator to run free at its natural frequency.

You will insert a specific casualty into your circuit and then follow the normal procedure for tracking down the trouble. Check your circuit to insure that it is operating correctly before inserting a casualty.

Trouble—Simulate a non-emitting tube. Turn off power to the chassis. At A-26L disconnect lead to V6. This opens the cathode circuit of V6B at pin 6. Apply power to the chassis and observe by means of the 'scope that there is no output. Observe that the positive trigger is available at grid pin 4 of V6. With the voltmeter, measure the d-c voltage from pin 4 to ground. Note that the voltage is zero, indicating that the circuit is not oscillating. Turn off power to the chassis and resolder the cathode lead. Turn on power to the chassis and remeasure the grid voltage. The negative voltage indicates the circuit is now oscillating.



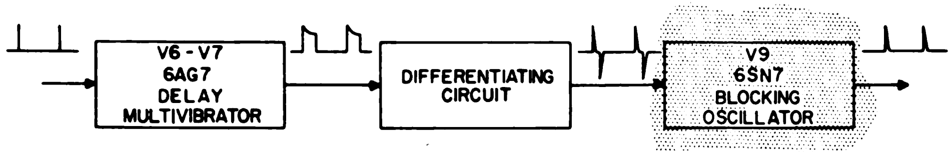
171.—"Blocked" blocking oscillator—trouble shooting.

Now you and your partner will insert troubles into each other's circuits—anywhere in the circuits you have covered to date. Be sure to use the logical trouble-shooting procedure if you expect to do fast servicing. Get the instructor's approval before inserting the trouble.

After trouble shooting is completed, restore the circuit to normal by removing the jumper, and check to insure that it is operating correctly.

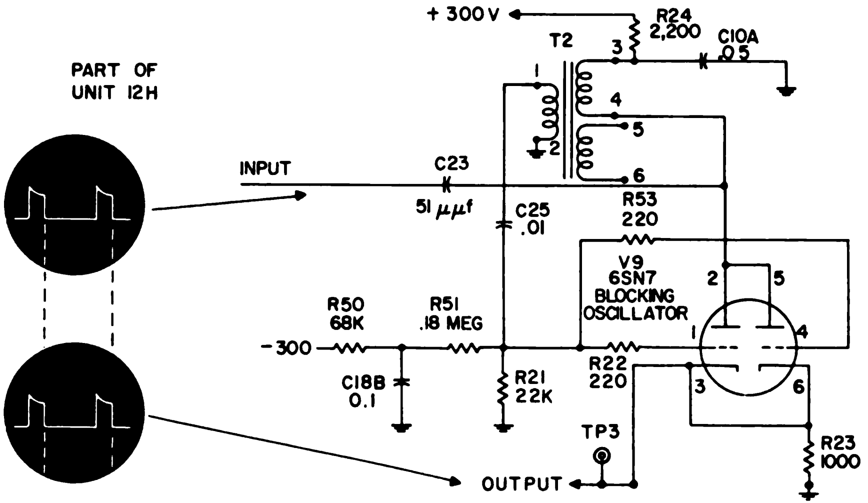
Applications

The first example of a blocking oscillator in fire control radar equipments is from Radar Equipment Mark 25 Mod 3. This circuit functions to generate a short-duration pulse to trigger the following circuit.



172. —Use of blocking oscillator in Mark 25 Radar.

In the accompanying blocking oscillator schematic, you will note several similarities to the one in your special circuits chassis. The input trigger is applied to the grid circuit through a transformer. The output pulse is taken from across the cathode resistor. In both cases, a 6SN7 tube is used, but in this example, the two triode sections of V9 are operated in parallel.



173. —Blocking oscillator in Mark 25 Radar.

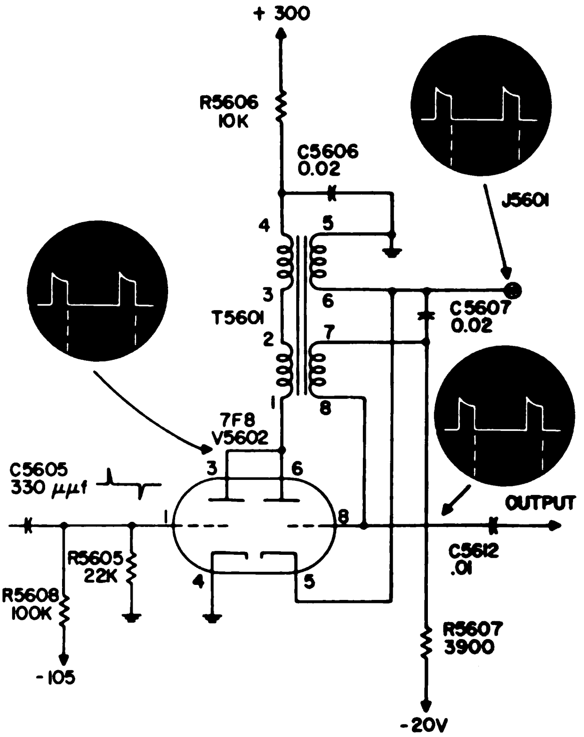
A positive 23-microsecond square wave is differentiated in the coupling circuits between V6-V7 and V9. The positive differentiated pulse at terminal 4 of T2 is inverted in the transformer and the negative pulse at terminal 1 is applied to the grids of V9. The negative pulse will have no effect on conduction in the tube because it is biased below cut-off by negative bias from the -300 volt power supply. The negative differentiated pulse, at the end of the 23 microseconds, is inverted in T2 and is applied as a positive trigger to the grids of V9. The positive pulse raises the grid voltage above cut-off and the tube begins to conduct. The plate-to-grid feedback circuit, 3-4 to 1-2 winding of T2, quickly drives the circuit into saturation. When saturation is reached, there is no longer a rate of change in the current flowing in the 3-4 winding of T2. The induced voltage on the grids of V9 tends to drop to zero. The magnetic field in T2 collapses, inducing a voltage of negative polarity that is applied to the grids. This voltage adds to the negative bias voltage and drives the tube below cut-off. C25 will now discharge to the bias voltage, and the tube will remain cut off until another trigger is applied.

BLOCKING OSCILLATOR

Applications (Continued)

Shown below is the schematic representation of a typical blocking oscillator used in the Mark 35 Radar for Gun Fire Control System Mark 56.

Note that a buffer amplifier is used just before the blocking oscillator. This circuit serves the same function as the buffer amplifier in your chassis. It isolates the large signal variations that appear in the blocking oscillator from the previous stages.



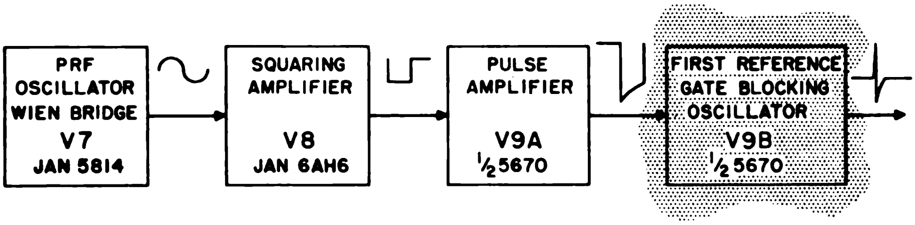
174.—Blocking oscillator in Mark 35 Radar.

Note also that this blocking oscillator utilizes four windings in the transformer. Two windings are in the plate circuit and one each in the grid and cathode circuits. Polarization of the transformer is determined by the numbers appearing at the end of each winding in the same manner that you learned in this topic.

The buffer amplifier is biased from the -105 volt power supply, and only a positive signal affects the tube. When V5602A conducts, it passes current through the 1-2 and 3-4 winding of transformer T5601. This causes terminals 6 and 8 to go positive. Terminal 6, connected to the cathode is driven positive. Terminal 8 is connected to the grid and to the 6-5 winding of the transformer through capacitor C5607 The grid will be driven positive and due to the circuit, it goes more positive than the cathode. This action drives the tube into conduction. Because of feedback through the transformer windings to the grid, the circuit reaches saturation rapidly. When the circuit reaches saturation, the magnetic field built up around the transformer windings starts to collapse. This reverses the polarities on the transformer, which in turn drives the grid negative, and the tube is driven sharply into cut-off. The tube is held in cut-off by the -20 volt bias on the grid until the next trigger pulse arrives. The negative feedback to the cathode through the 6-5 winding of T5601 aids in delaying saturation of the circuit, thus aiding in the development of a pulse of desired duration.

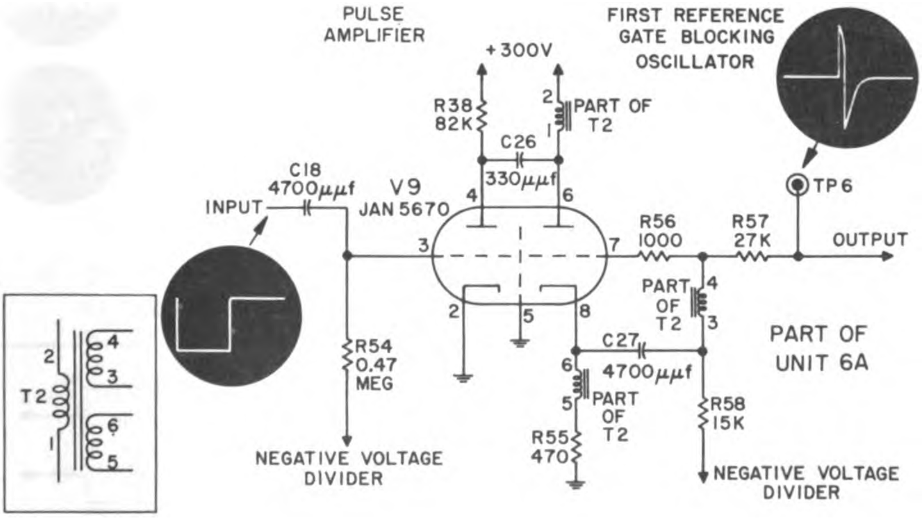
Applications (Continued)

The next example of a blocking oscillator in fire control radar equipments is taken from Radar Set AN/SPG-48. This oscillator is "blocked" by negative bias obtained from a voltage divider in the -300 volt power supply. When triggered, it functions to develop a positive gating pulse of short duration. This gating pulse is one of the signals applied to a coincidence amplifier, the next stage of Unit 6A in this radar.



175.—Use of blocking oscillator in AN/SPG-48 Radar.

The output of pulse amplifier V9A is an amplified square wave that undergoes some differentiation in the coupling circuit to the blocking oscillator V9B. When plate current begins to flow in V9A, a negative pulse is developed across the 1-2 winding of T2. This pulse is inductively coupled to the other windings of the transformer, making terminals 4 and 6 positive. The cathode goes positive with respect to ground and the grid goes positive with respect to the cathode. Once current begins to flow in the 6-7-8 section of V9, regenerative action drives the circuit into saturation. The resulting collapse in the magnetic field of the transformer produces a reversal in the polarity of the voltage at the terminals, and the tube is driven rapidly to cut-off. Once the grid goes below cut-off, the biasing circuits keep it there until the next trigger is applied.



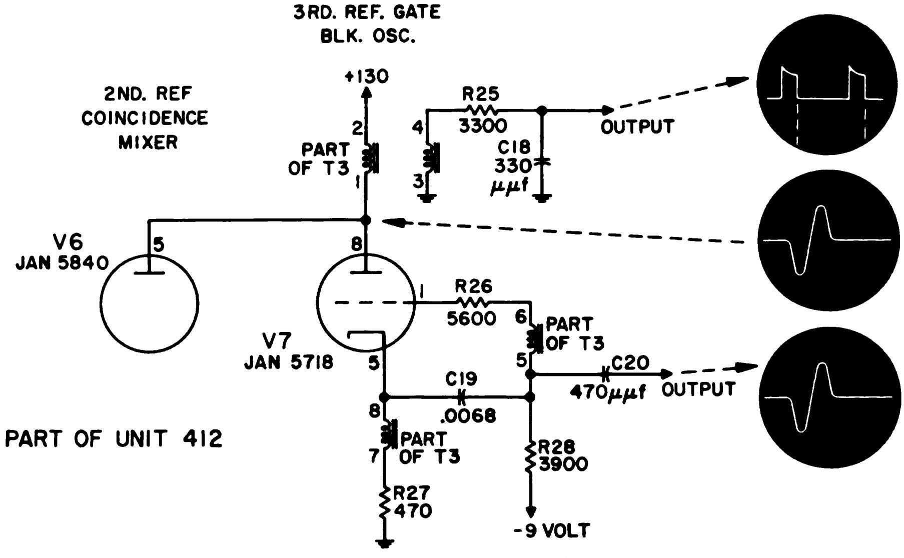
176.—Blocking oscillator in AN/SPG-48 Radar.

Applications (Continued)

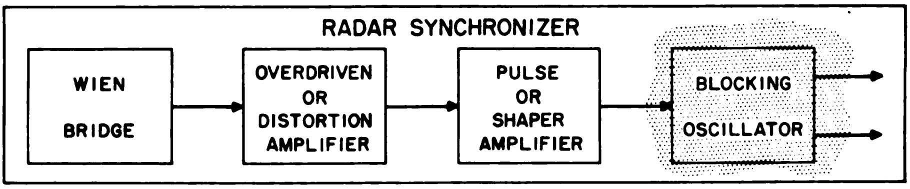
On this page is shown another application of blocking oscillators as used in fire control radar equipments. This circuit will be encountered in the AN/SPG-50 fire control radar.

Notice that this blocking oscillator is also biased to cut-off by -9 volts from the negative power supply. Note also that there are four windings of the transformer T3 used in this blocking oscillator.

Initially, the blocking oscillator receives its signal from the preceding stage. This signal is felt through the 1-2 winding and is coupled by the 5-6 winding to the grid of the blocking oscillator. Since the input signal drives terminal 1 negative, terminals 4-6-8 go positive due to coupling through the transformer. Thus, the control grid is driven positive and the blocking oscillator is brought into operation. Circuit operation is essentially the same as in the previous examples. However, there are two outputs from this circuit. One is obtained from the 3-4 winding of T2 and the other is taken from terminal 5 of the 5-6 winding. Each of these outputs is used to initiate action in two separate circuits of the synchronizing system of the radar.



177. — Blocking oscillator in AN/SPG-50 Radar.



178. — Use of blocking oscillator in AN/SPG-50 Radar.

BLOCKING OSCILLATORS

Review

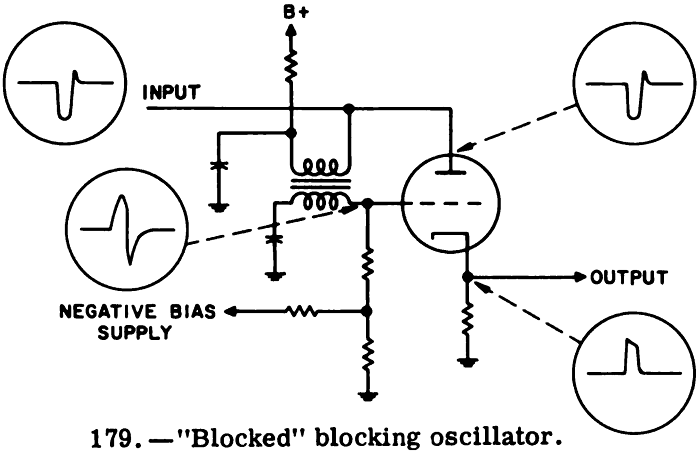
In this topic, you have become familiar with the operation of the blocking oscillator.

Some of the basic facts associated with blocking oscillators are:

1. The blocking oscillator may be either free-running or triggered.

2. The output frequency of the free-running type blocking oscillator will not be stable. The triggered blocking oscillator will produce a stable output if the triggers are at a higner frequency than the natural frequency of the free-running blocking oscillator.

3. Most blocking oscillators used in fire control radars are "blocked" by negative bias applied to the grid circuit.



179.—"Blocked" blocking oscillator.

4. "Single-kick" is a term applied to a blocking oscillator that is biased to cut-off and is triggered to produce a single cycle of operation for each trigger.

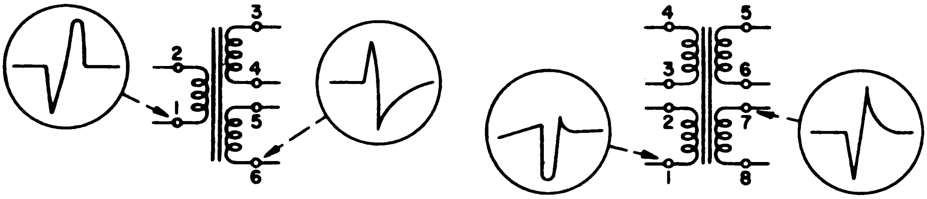
5. A transformer is used for feedback between the plate and grid circuits of a blocking oscillator.

6. The transformer used in a blocking oscillator may have two, three, or four windings. In transformers having two windings, these windings are in the plate and grid circuits. In transformers having more than two windings, the additional windings may be in the cathode or output circuits.

7. The output from a blocking oscillator may be taken from the plate, grid, or cathode circuits, or from a separate output winding in the blocking oscillator transformer. The output used depends upon the polarity and amplitude requirements of the signal for the next stage.

Review (Continued)

8. The conventional system for numbering the terminals of the transformer used in a blocking oscillator circuit is that all of the even-numbered terminals will be of one polarity and all of the odd-numbered terminals will be of the opposite polarity.



180.—Polarities of transformer terminals in a blocking oscillator circuit.

9. Regenerative feedback in the blocking oscillator drives the circuit into saturation.

10. The output of the blocking oscillator may be used as a trigger pulse or as a gating pulse.

11. Blocking oscillators are encountered in the synchronizing and ranging circuits of radar equipments.

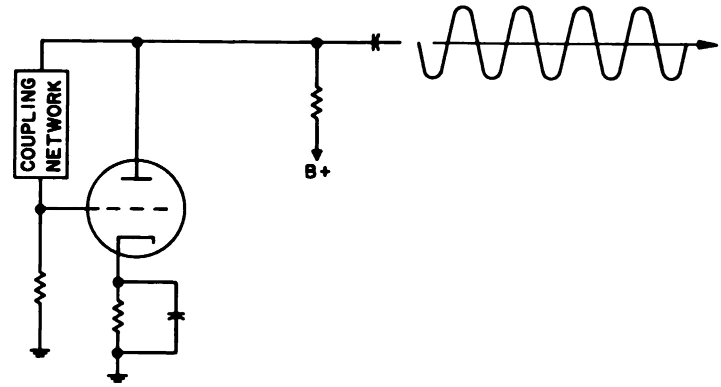
Notes

TOPIC 9: MULTIVIBRATORS

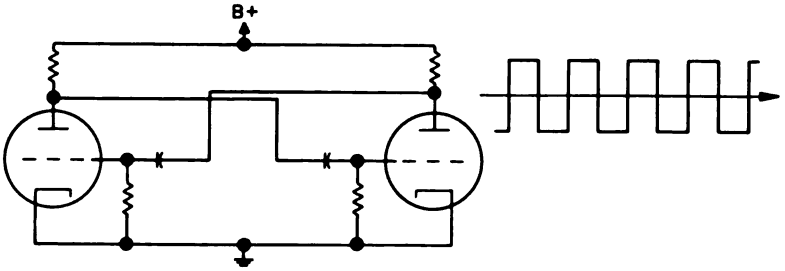
What a Multivibrator Is

The multivibrator, used very widely in radar equipment, is nothing more than an oscillator which puts out a square wave. An oscillator is merely an amplifier which has its plate signal fed back in proper phase and amplitude to the control grid. The output of an oscillator is normally a sine wave.

A multivibrator consists of two sections, and in the typical multivibrator, the plate of each tube is coupled to the grid of the other tube by means of capacitors. When the circuit oscillates, it puts out square waves which may be obtained from either or both of the plates.



181. —Oscillator.



182. —Multivibrator.

MULTIVIBRATORS

General Purposes

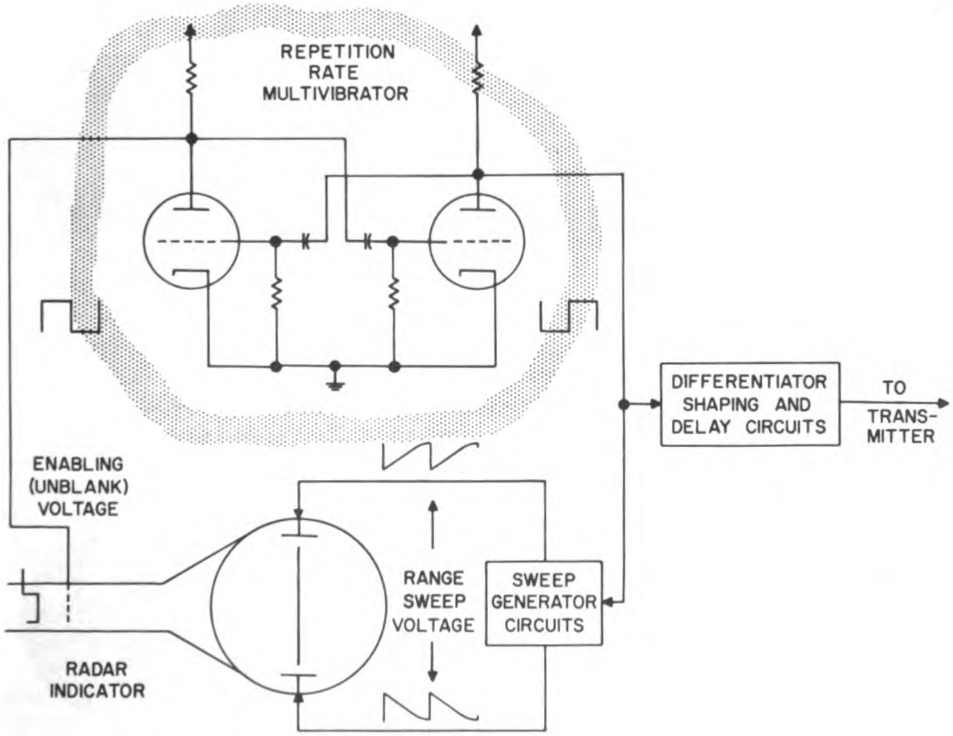
Multivibrators have a variety of functions in fire control radar equipments. All of them produce a square wave which can be utilized for a number of purposes.

Some fire control radars use a multivibrator as the source of the pulse repetition frequency (PRF). When used in this manner, the output waveform can be differentiated and shaped to trigger succeeding circuits in the radar, and at the same PRF. The PRF signal generated can be used to trigger other circuits or multivibrators which may be used to achieve a desired delay in the occurrence of other signals in the equipment. Some of these signals may be for range determination or for triggering of the transmitter.

The positive output of a multivibrator may also be used as an enabling (unblanking) pulse to the radar indicators so that video signals may be seen on the screen.

Another use of multivibrators is to trigger sweep generator circuits which produce the range sweeps (time base) on the screen of the radar indicator.

These are some of the uses of multivibrators in fire control radars. You will encounter them throughout radar equipments serving functions other than those described here.

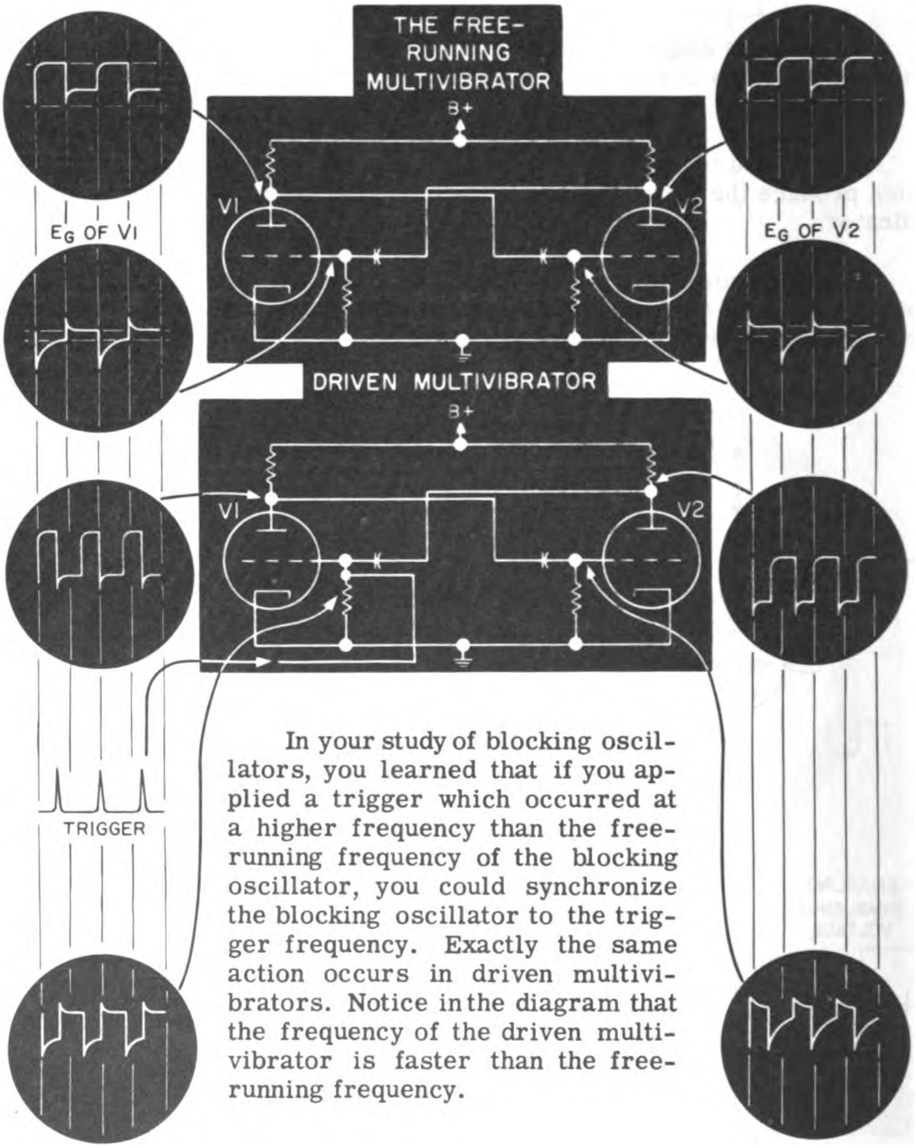

REPETITION RATE MULTIVIBRATOR
ENABLING (UNBLANK) VOLTAGE
RADAR INDICATOR
RANGE SWEEP VOLTAGE
SWEEP GENERATOR CIRCUITS
DIFFERENTIATOR SHAPING AND DELAY CIRCUITS
TO TRANSMITTER

183. —Uses of multivibrator output.

Multivibrator Types

A multivibrator may be considered as a "square-wave oscillator" since it puts out a waveform with vertical sides and a horizontal top and bottom. There are many varieties of multivibrators used in fire control radar equipment.

The two basic types of multivibrators are free-running and driven. The free-running type puts out a continuous series of square waves when voltage is applied to the circuit. The repetition frequency of these square waves is determined by the circuit components. A free-running multivibrator may be driven by triggers that have a higher frequency than the free-running frequency of the multivibrator.



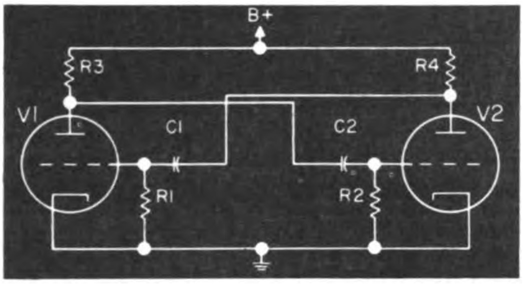
In your study of blocking oscillators, you learned that if you applied a trigger which occurred at a higher frequency than the free-running frequency of the blocking oscillator, you could synchronize the blocking oscillator to the trigger frequency. Exactly the same action occurs in driven multivibrators. Notice in the diagram that the frequency of the driven multivibrator is faster than the free-running frequency.

184. —Comparison of free-running and driven multivibrators.

MULTIVIBRATORS

The Free-Running Multivibrator

To begin, you will first study the basic free-running multivibrator circuit.



185. —Free-running multivibrator.

The following fundamental properties of vacuum-tube circuits are repeated as an aid in the analysis of multivibrator action:

1. A rise in grid voltage causes an increase in plate current through the tube and, conversely, a fall in grid voltage causes a decrease in plate current.

2. An increase in current through the plate load resistor causes the voltage on the plate to decrease. A decrease in plate current causes the voltage at the plate to increase.

3. The voltage across the capacitor in an R-C coupling circuit cannot change instantaneously.

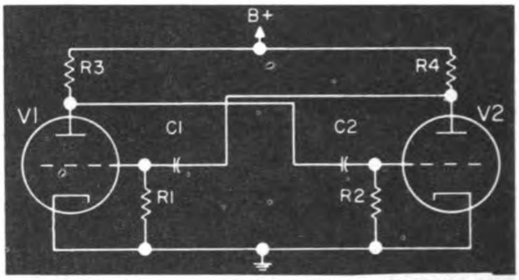
4. The polarity of the voltage that appears across a resistor may be determined by remembering that electrons always flow from the negative end to the positive end.

5. A capacitor requires a definite time to charge or to discharge through a resistor. A measure of this time, called the time constant, is found by multiplying the resistance by the capacitance.

The name "free-running" comes from the fact that this circuit goes into action as soon as the power supply voltages are applied. The multivibrator will continue to put out square waves until the power supply is turned off. When voltage is applied to the free-running multivibrator circuit, current will begin to flow in both triode sections. Even if the components in each of the two sections are shown as identical in values, an unbalance will exist and the currents in the two sections will be slightly different. The initial difference in current flow in the two sections is essential in order that multivibrator action will begin.

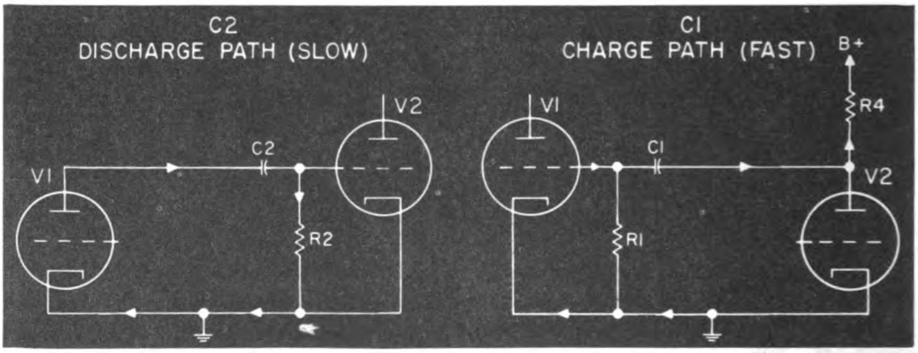
Some free-running multivibrator circuits will have an unbalance in components in the circuit design. The unbalance will exist, even though it is not included in the design. Some of the sources of the necessary unbalance are slight differences in the emission of the tube sections, or slightly different values of components, or it may be a combination of these differences. The unbalance will result in more conduction in one triode than in the other and the multivibrator action has begun.

The Free-Running Multivibrator (Continued)



186. —Free-running multivibrator.

For our analysis of the operation of the free-running multivibrator, let us assume that the conduction in V1 is greater than the conduction in V2. The voltage at the plate of V1 will be lower than the voltage at the plate of V2. The voltage across C2-R2 will be less than the voltage across C1-R1. The voltage across C2-R2 will decrease with an increase in the plate current through V1. C2 will have a discharge path from one plate of the capacitor through R2 and V1 to the other plate of the capacitor. C2 discharge current will drive the grid of V2 in a negative direction. This will reduce the current flow in V2, and the voltage across C1-R1 will increase, causing a further increase in current through V1 and a further drop in the voltage at the plate of V1. C2 continues to discharge and the negative voltage across R2 results in V2 being cut off. The resulting increase in the plate voltage of V2 increases the voltage across C1-R1 and makes V1 conduct heavily. The plate voltage of V2 rises to the B+ level and the voltage at the plate of V1 falls to some low value. This condition will continue for a time, dependent upon the circuit constants.

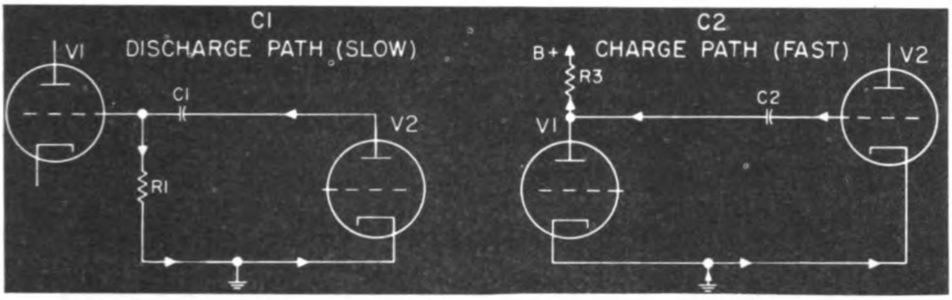


187. —Free-running multivibrator operation (I).

After one R-C time constant, the voltage across R2 will have been reduced to 37 percent of the voltage change at the plate of V1. The current through R2 is reduced and the voltage at the grid of V2 becomes less negative. This process continues, and the voltage at the grid of V2 rises above the cut-off level and V2 goes into conduction. The voltage at the plate of V2 drops sharply and this voltage change is impressed across C1-R1, driving the grid of V1 negative. Plate current in V1 is cut off and the voltage at its plate rises toward B+ level. This change in voltage is impressed across C2-R2 and drives the grid of V2 positive. C2 charges through

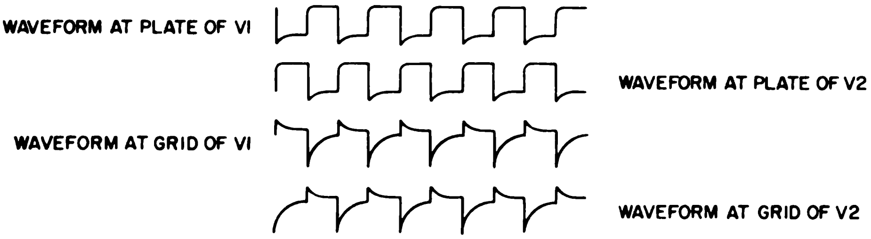
The Free-Running Multivibrator (Continued)

R3, the power supply, and the cathode-to-grid resistance of V2. C1 discharges from one plate through R1 and through V2 to the other plate of the capacitor. The discharge current from C1 develops a negative voltage on the grid of V1. The condition now exists with V2 conducting heavily and V1 cut off. This condition will remain until C1 is discharged to the extent that the reduced current through R1 does not develop enough grid voltage to keep the tube below cut-off. V1 starts to conduct and this initiates the next half-cycle, which has V1 conducting and V2 cut off.



188. — Free-running multivibrator operation (II).

Conduction in V1 produces the negative portion of the square wave at its plate. The positive portion of the square wave is produced when V1 is cut off. A square wave of opposite polarity is produced at the plate of V2. The cut-off time of V2 and the conducting time of V1 are determined by the R-C time constant in the discharge path of C2 and the cut-off voltage of V2. The cut-off time of V1 and the conducting time of V2 are determined by the R-C time constant in the discharge path of C1 and the cut-off voltage of V1.



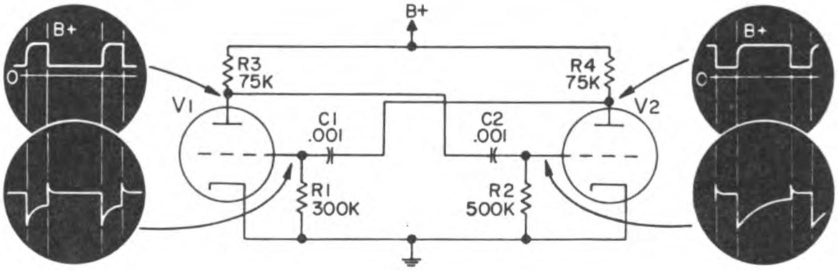
189. — Free-running multivibrator waveforms.

The irregularities in the square waves are the result of action of C1 and C2. The charging current for C1 produces the positive peaks on the waveform at the grid of V1, the rounding of the leading edge of the positive portion of the waveform at the plate of V2, and the negative peak on the leading edge of the negative portion of the waveform at the plate of V1. On the next half-cycle, the corresponding irregularities are produced by the charging current of C2. The discharge of C2 produces the positive-going, curved portion of the waveform at the grid of V2, and the discharge of C1 produces the corresponding portion on the next half-cycle of the waveform at the grid of V1.

The Free-Running Multivibrator (Continued)

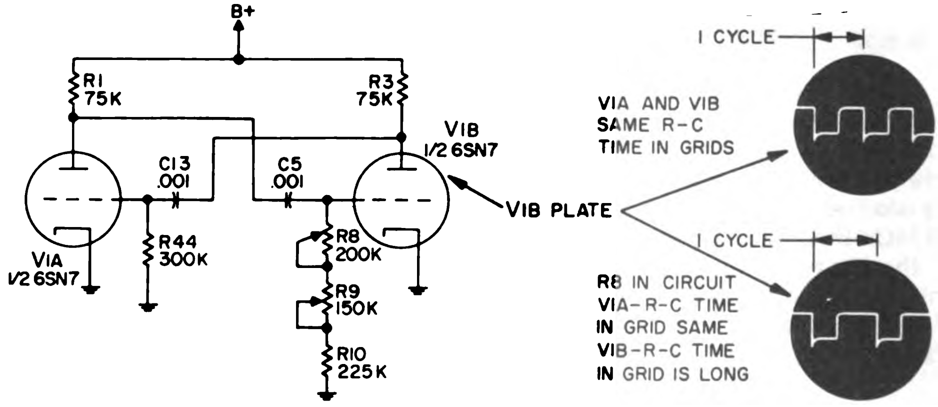
Notice that the previously illustrated multivibrator has symmetrical output; that is, the length of the cut-off time is the same for each tube. This means that the time constants of the capacitors' discharge paths and the cut-off voltages of the tubes are the same for both halves of the circuit.

Very often in radar applications, it is desired to obtain short pulses with relatively long periods of time between pulses. This can be accomplished by making the time constant of the discharge path of one capacitor long with respect to the time constant of the other, as shown below.



190. --Free-running multivibrator operation (III).

The schematic shown below is essentially the same circuit as the one above. In this circuit, the time constant is variable by means of the potentiometers, R8 and R9. If R8 is set to zero resistance, as shown, then R9 can be adjusted so that the time constants of each grid will be equal. At this time, the output waveform will be symmetrical and of a definite frequency. Now, if R8 is turned to the other limit, the time constant of the grid circuit of V1B will have been increased by 67 percent. The output waveform is no longer symmetrical, since the time constants are no longer equal. V1A will now remain cut off for the same length of time as before and V1B will conduct for the same length of time. However, because of the long time constants in the grid of V1B, it will remain in cut-off 67 percent longer than before. Thus, the output frequency has been decreased. You will encounter this circuit later in the applications of multivibrator circuits in fire control radar equipments.

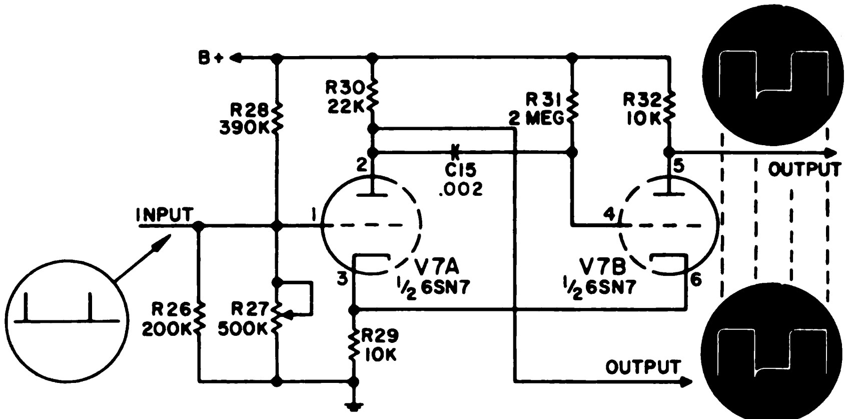


191. —Free-running multivibrator operation (IV).

One-Shot Multivibrator

Now that you are familiar with the free-running type of multivibrator, you are ready to study the driven type of multivibrator. In your work on fire control radar equipments, you will frequently come across several types of driven multivibrators. The action of any one of these will be very similar to the action of the free-running type. The only difference lies in the fact that the driven multivibrator must be started by some external means and then operates until a stable condition is reached.

You will work with the one-shot multivibrator in the special circuits chassis. You will examine its operation and get some practice trouble shooting the circuit. First of all you will want to know how this circuit works.



192. —One-shot miltivibrator operation (I).

The one-shot multivibrator is a driven type of multivibrator that puts out a cycle of square-wave voltage for each trigger put into it. This is the source of the descriptive term "one-shot" in its title. In this circuit, the plate of V7A is coupled to the grid of V7B through C15 in the same manner as used in the free-running multivibrator. The coupling capacitor, as found in free-running multivibrators between the other plate and other grid, has been omitted. A cathode resistor common to both triode sections of V7 provides the coupling from V7B to V7A. A multivibrator with this manner of coupling may be referred to as a "cathode-coupled" multivibrator.

The one-shot multivibrator will have a quiescent state of one section conducting and the other section cut off. A positive trigger applied to the cut-off section will result in one cycle of operation. The circuit then returns to its static state, with one section conducting and the other cut off until the next trigger is applied.

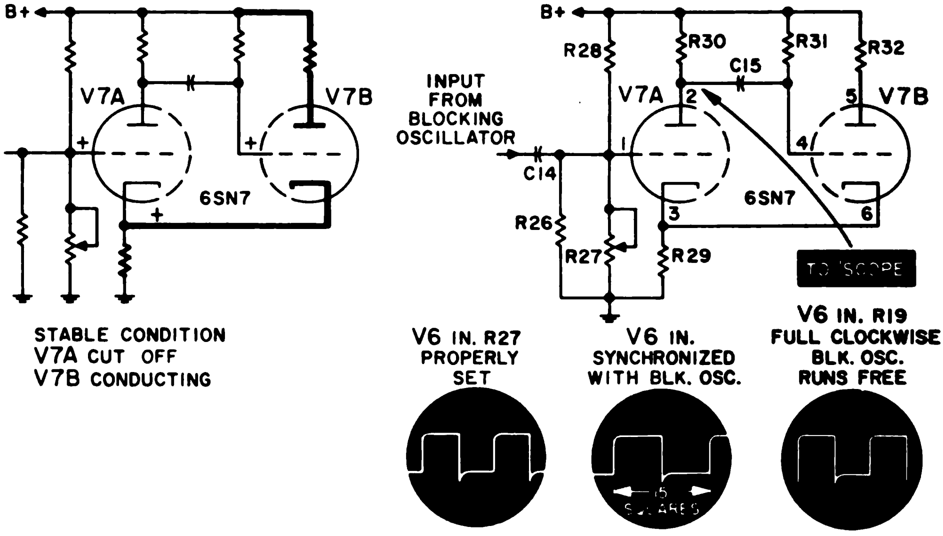
When voltages are applied to the circuit, it will reach a stable condition with V7A cut off and V7B conducting. There are several reasons for this condition being attained. One of these is the biasing network in the grid circuit of V7A which consists of R28 in series with the parallel resistors, R26 and R27. This network alone would permit conduction in V7A.

One-Shot Multivibrator (Continued)

However, there is another action to be considered. Note that the grid of V7B is connected to B+ through R31. This means that V7B will also conduct. Now notice that the plate load resistors (R30 and R32) of V7 are of different values. You see that the plate load for V7B is less than one-half the value of the plate load for V7A. Thus, a great deal more current flows through V7B than through V7A. This comparatively large current produces a large drop across the common cathode resistor, R29. This large drop is enough to bring the grid-to-cathode potential of V7A into cut-off. This action also brings the circuit to its stable condition, and an input trigger is required to cause the circuit to operate.

The positive trigger applied to grid 1 must be of sufficient amplitude to bring V7A out of cut-off. When a trigger of this amplitude is received, V7A will be driven into conduction. The resulting drop in voltage at plate pin 2 of V7A is coupled across C15 and impressed on the grid of V7B, and V7B will be cut off.

The cut-off time of V7B and the conducting time of V7A will be determined by the time required for C15 to discharge until the grid voltage of V7B is again above cut-off. C15 had been charged to the B+ level (less the drop across R29) during the cut-off time of V7A. It now discharges through R31. The discharge current through R31 makes the grid negative with respect to the cathode. The discharge of C15 follows the universal time-constant curve. After one R-C time, the charge across the capacitor has been reduced by 63 percent and the discharge current through R31 will have been reduced by the same percentage. Continued discharge and reduction in the discharge current permits the voltage on the grid of V7B to come out of the region of cut-off. The tube goes back into conduction and increases the voltage drop across R29, the common cathode resistor. The grid-to-cathode voltage of V7A goes below cut-off and conduction is stopped in this section of the multivibrator. This condition remains static with V7A cut off and V7B conducting until the next trigger is received.



193. —One-shot multivibrator operation (II).

MULTIVIBRATORS

Experiment—One-Shot Multivibrator

In this experiment, you are going to check the voltages in the multivibrator circuit when no trigger is applied. You will then observe the waveforms when a trigger is applied from the blocking oscillator at the frequency of the Wien bridge. You will then trigger the multivibrator with the blocking oscillator running free.

For this experiment, you will require an oscilloscope and multimeter.

1. Check that the Wien bridge is producing a sine wave and that the blocking oscillator is synchronized with the Wien bridge.

2. Connect 'scope probe to plate pin 2 of V7A and adjust R27 to obtain a square wave. This insures that the bias on V7A is not too large to prevent triggering of the multivibrator.

3. Remove V6; note that there is no output from the multivibrator.

4. With a voltmeter, read the voltage-to-ground potential from the following pins of V7:

   a. Grid 1
   b. Cathode 3
   c. Plate 2
   d. Grid 4
   e. Cathode 6
   f. Plate 5

5. Note that the grid-to-cathode potential of V7A is negative and the plate potential is equal to B+. This indicates that V7A is cut off.

6. Notice also that the grid-to-cathode potential of V7B is very nearly zero and the plate potential is much less than B+. This indicates that V7B is conducting.

7. Now insert V6 and connect 'scope probe to plate pin 2 of V7. With the blocking oscillator synchronized to the Wien bridge, adjust the horizontal amplitude (gain) of the 'scope so that one cycle of the square wave covers 15 small squares of the grid system on the face of the 'scope.

8. Now cause the blocking oscillator to run free—R19 full clockwise.

9. Note the waveform on the 'scope is no longer synchronized. This indicates a frequency change at the plate of V7A (pin 2). Adjust 'scope for a stationary waveform and note that the positive portion is longer than it was in step 7 above, while the negative portion is of the same duration.

10. From the above, it should be seen that the output frequency of the one-shot multivibrator is dependent upon the frequency of the trigger.

Experiment—Free-Running Multivibrator

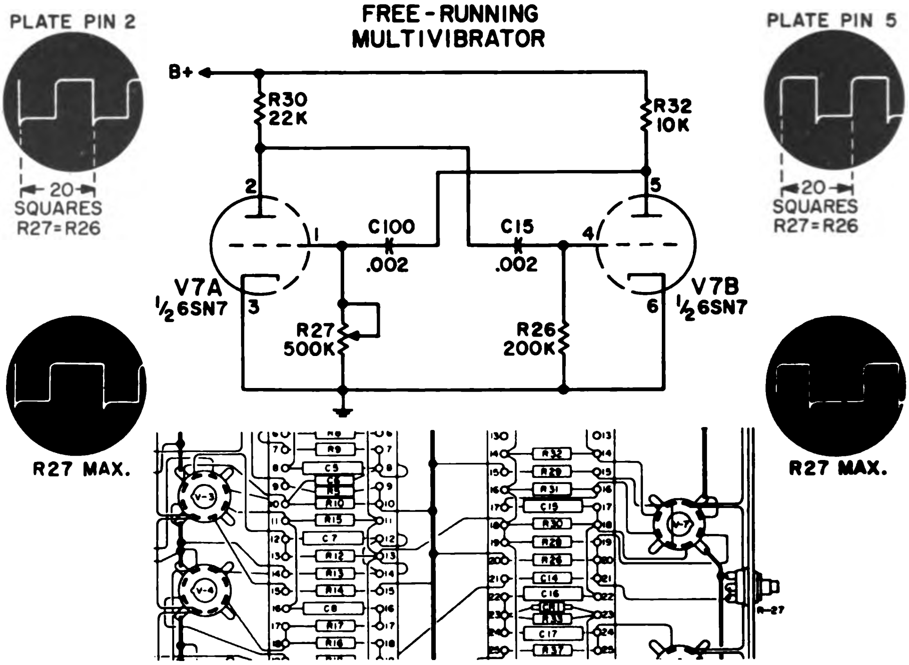
For this experiment, you will require the following items:

1. 6SN7 (V7)
2. .002 mfd cap. (C100)
3. Oscilloscope
4. Multimeter

You will convert the multivibrator in your chassis to the free-running type by making the following modifications to the circuit:

1. Remove all power from the chassis.
2. Disconnect R26 at terminal B-20R.
3. Disconnect R28 at terminal B-19R.
4. Disconnect R31 at terminal B-16R.
5. Disconnect C14 at terminal B-21R.
6. Connect the loose end of R26 to B-16R.
7. Connect your .002 mfd capacitor (C100) between terminals B-14R and B-19R.
8. Connect a jumper from ground to terminal B-15R (across R29).

Now check the completed circuit against the accompanying schematic. Before proceeding to the experiment, correct any wiring errors.



194. —Free-running multivibrator—test setup.

MULTIVIBRATORS

Experiment—Free-Running Multivibrator—Checking Waveforms

You are now going to check the output waveforms of the free-running multivibrator that you have just wired into your chassis.

1. Power "OFF." With multimeter, adjust R27 to equal the resistance of R26 (approximately 200K ohms).

2. Insert V7 (6SN7) and connect 'scope probe to plate of V7A (pin 2).

3. Energize chassis and 'scope.

4. Adjust 'scope controls to obtain one complete cycle of the square wave. Notice that both the positive and negative portions are very nearly equal in time duration. This is because the time constants in the grid circuits of V7A and V7B are equal (or nearly so).

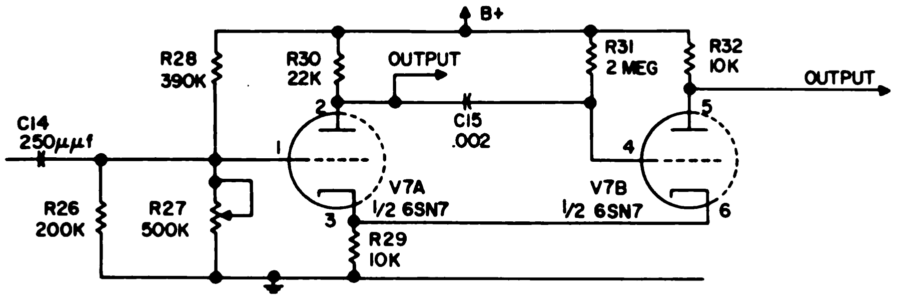
5. Adjust horizontal amplitude (gain) so that one cycle of the square wave covers 20 small squares of the grid system on the 'scope face.

6. Now set R27 for maximum resistance (full clockwise). Notice that the waveform on your 'scope is no longer synchronized. DO NOT move the horizontal amplitude (gain) control. Adjust other 'scope controls to obtain a stationary square wave of one cycle duration.

7. Now note that the square wave is no longer symmetrical. The negative portion is the same as before, but the positive portion lasts longer. This is due to the increased time constant of the grid of V7A which holds the tube in cut-off for a longer time. Also note that one cycle of the square wave extends further across the 'scope than it did in step 5 above. From this, you find that by increasing the time constant in one grid circuit, you can decrease the frequency of the free-running multivibrator.

8. Remove power from the chassis and rewire to a one-shot multivibrator.
    - a. Disconnect jumper from B-15R and ground.
    - b. Remove capacitor C100 from B-14R and B-19R.
    - c. Disconnect R26 from B-16R.
    - d. Connect C14 to B-21R.
    - e. Connect R31 to B-16R.
    - f. Connect R28 to B-19R.
    - g. Connect R26 to B-20R.

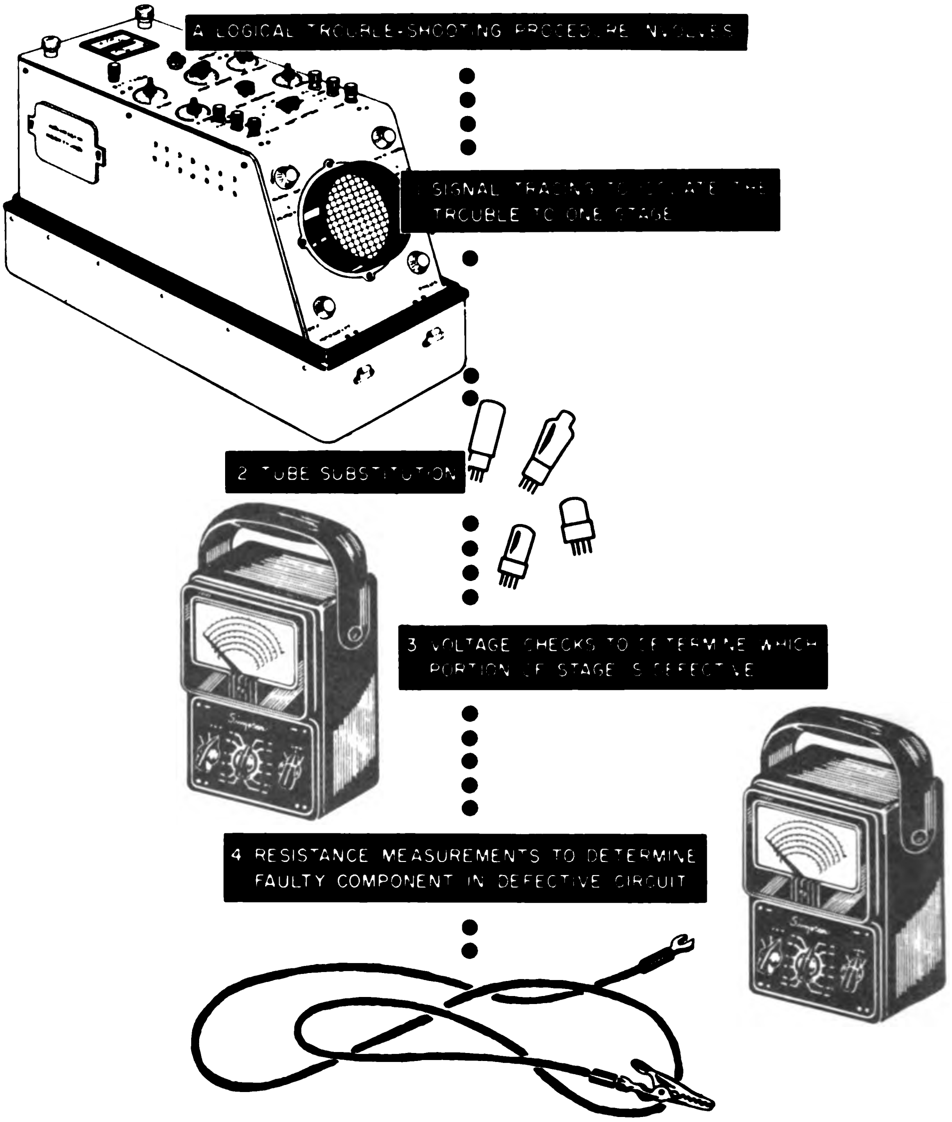
Your circuit should agree with the schematic shown below.



195. — One-shot multivibrator circuit.

Experiment—Trouble Shooting

The procedure used to trouble shoot a multivibrator is no different than that used to trouble shoot a conventional amplifier. Very briefly, this procedure involves isolating the trouble to the defective stage (usually by signal tracing), and then isolating the defect to a particular component in that stage by voltage and resistance measurements.


A LOGICAL TROUBLE-SHOOTING PROCEDURE INVOLVES
1 SIGNAL TRACING TO ISOLATE THE TROUBLE TO ONE STAGE
2 TUBE SUBSTITUTION
3 VOLTAGE CHECKS TO DETERMINE WHICH PORTION OF STAGE IS DEFECTIVE
4 RESISTANCE MEASUREMENTS TO DETERMINE FAULTY COMPONENT IN DEFECTIVE CIRCUIT

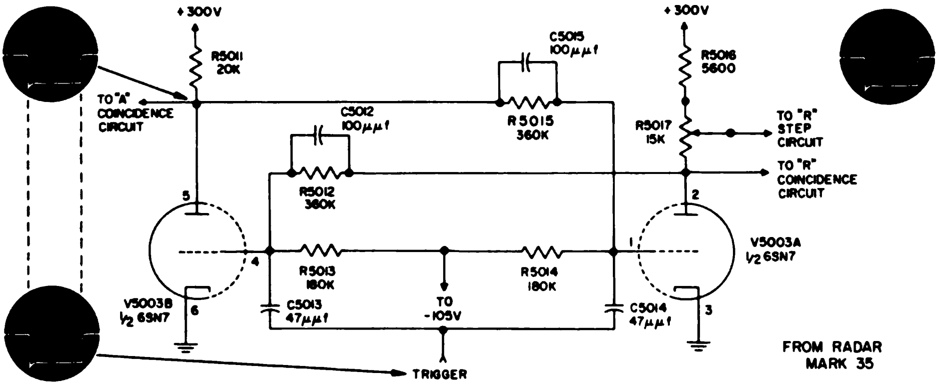
196. — Multivibrator trouble shooting procedure.

You and your partner will insert approved troubles into each other's circuits. You will then service the circuits, using the same logical trouble-shooting procedure previously used.

Other Types of Multivibrators

You have become acquainted with the two basic types of multivibrators, free-running and driven. In fire control radar equipments, you will encounter variations in these types. Some of the variations will be in name only. A free-running multivibrator may be referred to as a self-triggered multivibrator. Of the driven type, the one-shot will be the one most frequently encountered. Some of the names that you will find applied to this circuit will be one-shot, one-kick, single-shot, start-stop, and monovibrator. The operation of these one-shot multivibrators is very similar to that of the one-shot in the chassis. The only basic difference is that a negative bias is applied to one section to hold it cut off until a trigger is applied to the circuit.

Another type of multivibrator that you will encounter, but less frequently, is the "flip-flop" multivibrator. There are two stable conditions of operation of this circuit. A trigger is necessary to cause it to "flip" from one stable condition of operation to the other. The circuit remains in this second stable condition of operation until the next trigger is applied and then "flops" back to the original stable condition. This reversal from one stable condition to the other is the source of the term "flip-flop." Eccles-Jordan is another name sometimes applied to the circuit.



197. — Flip-flop multivibrator circuit.

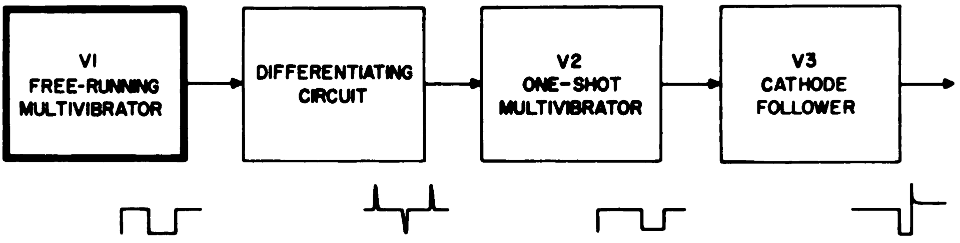
FROM RADAR
MARK 35

The example of the flip-flop multivibrator, given in the accompanying diagram, is taken from a fire control radar equipment, the Mark 35 Radar. This form of multivibrator uses direct coupling between plates and grids of alternate sections. After power is applied to the circuit, a stable condition will be reached with one section conducting and the other section cut off. A negative trigger is the flip-flop signal and is applied simultaneously to both grids. The trigger will result in the conducting section being cut off and multivibrator action will turn on the other section. The second stable condition is maintained until the next trigger. This second trigger will cause the circuit to revert to its original stable condition.

Another circuit that has a square wave as its output is the phantastron. It might be considered as a type of multivibrator. However, because of the importance of this circuit, it will be covered in the next topic, "The Phantastron."

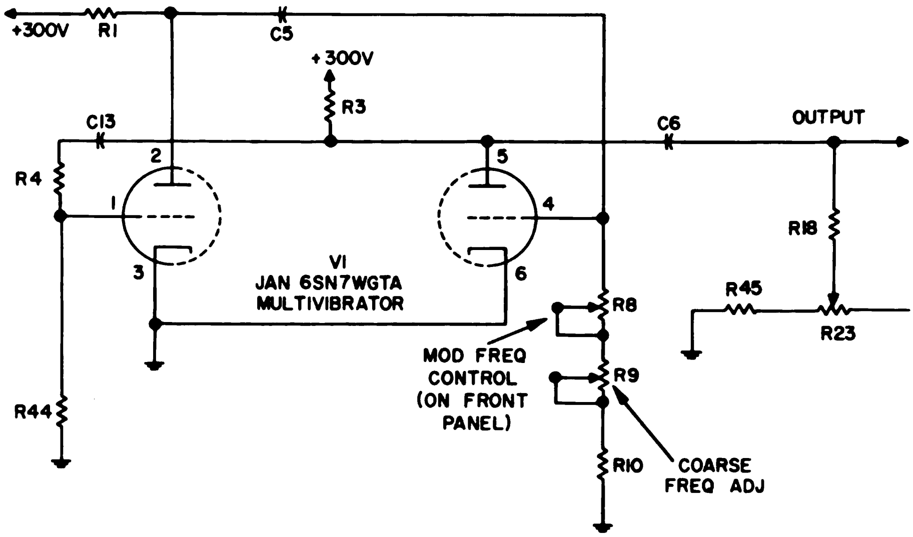
Applications

Only a very few of the many multivibrator circuits found in fire control radar equipments can be given here. The examples that are given will show some of the types and uses of this special circuit.



198. — Use of multivibrator in AN/SPG-34 Radar.

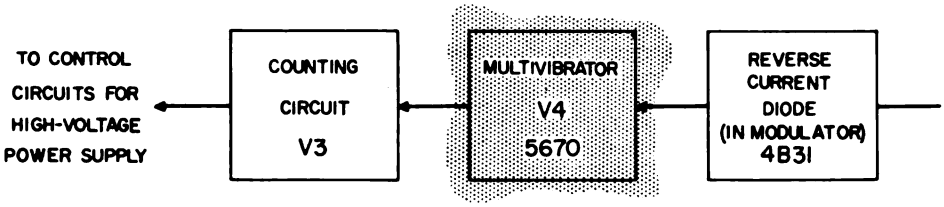
The first example is from Radar Set AN/SPG-34. This is a free-running multivibrator and is used to develop the pulse repetition frequency of this radar. R-C coupling circuits between the plates and grids of the two sections of V1 provide the positive feedback that is necessary for multivibrator action, and control the frequency of operation. The R-C circuit in the grid of the 4-5-6 section is variable by variation of R8 and R9. R9 is set to establish the mid-frequency, and R8, a front panel control, provides for changing the repetition rate during operation. The output of the multivibrator is differentiated by the R-C circuit composed of C6, R18, R23, and R45. The negative differentiated pulse is used to trigger the next stage.



199. — AN/SPG-34 Radar free-running multivibrator circuit.

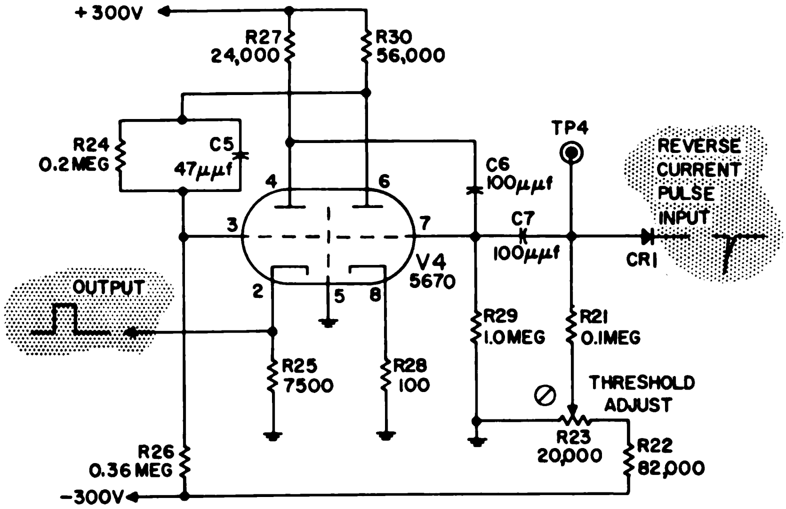
Additional information on the operation of this multivibrator was given on page 144. The operation of the two circuits is basically the same, although the one from Radar Set AN/SPG-34 has different component values.

Applications (Continued)


TO CONTROL CIRCUITS FOR HIGH-VOLTAGE POWER SUPPLY
COUNTING CIRCUIT V3
MULTIVIBRATOR V4 5670
REVERSE CURRENT DIODE (IN MODULATOR) 4B31

200. — Use of multivibrator in Mark 25 Radar.

The next example of the multivibrator in fire control radars is taken from Radar Equipment Mark 25 Mod 3. V4 is a one-shot, or a one-kick, multivibrator. You will notice that in the schematic the flow of information is not in the conventional manner. The input to this circuit is from the right and the output is on the left. In the quiescent state of V4, the negative voltage applied to grid 3, from the negative power supply, will cut off this section. Section 6-7-8 of the tube will be conducting heavily. Negative reverse current pulses from the radar modulator are the source of triggering voltages for this multivibrator. These negative pulses are applied to grid 7 when they exceed the negative voltage at the arm of R23. A negative pulse at grid 7 will cut off the 6-7-8 section of the tube and the 2-3-4 section will be driven into conduction. This condition is maintained for approximately 100 microseconds as determined by C6 and R29. After this time interval, the tube returns to its stable condition and remains until another negative pulse is applied to grid 7. The output is a positive pulse of 100 microseconds duration taken from cathode pin 2 of the tube.

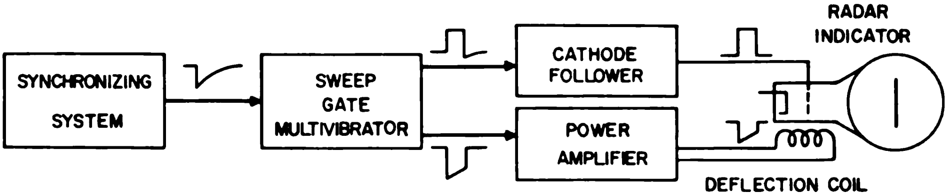


201. — Mark 25 Radar one-shot multivibrator circuit.

This circuit in identical form is found in the power supply control circuits of Radar Set AN/SPG-48.

Applications (Continued)

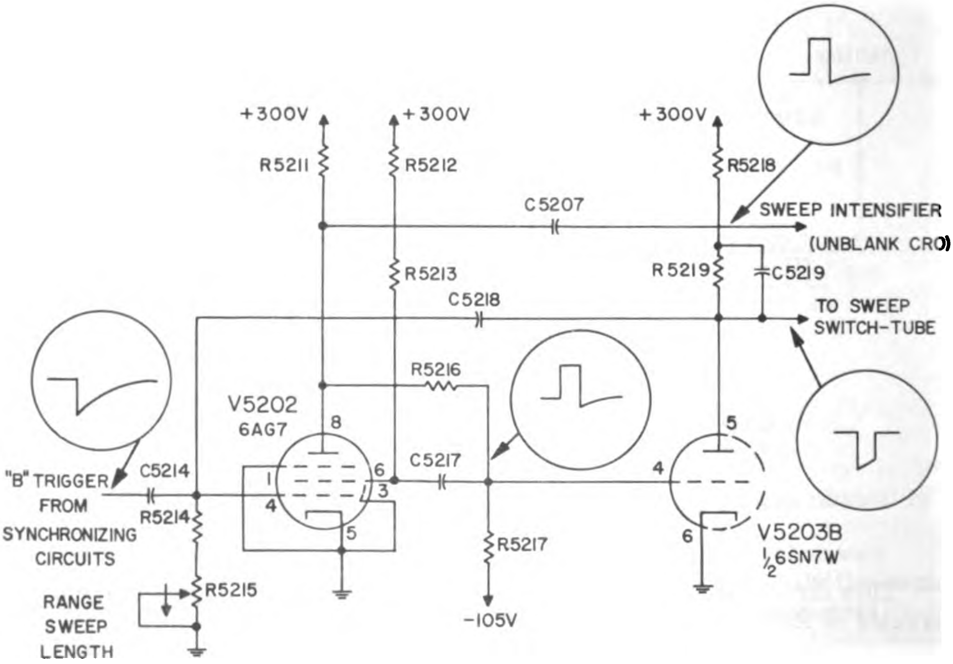
Shown below is a one-shot multivibrator circuit found in Fire Control Radar Equipment Mark 35.



202. — Use of multivibrator in Mark 35 Radar.

This multivibrator circuit has two outputs, one from each plate of the two tubes. The output at pin 8 of V5202 is applied to the cathode-ray tube and is used to unblank the indicator during sweep time. The other output from pin 5 of V5203B is applied to a power amplifier circuit and then to the deflection coil of the radar indicator to produce the sweep trace on the screen of the cathode-ray tube.

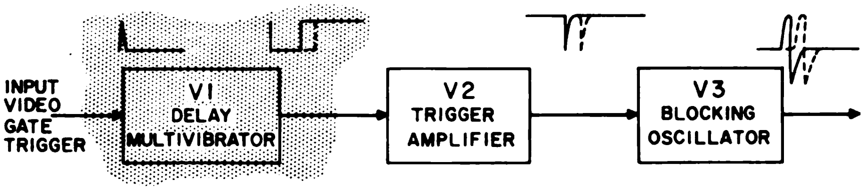
Normally, V5202 is conducting, and V5203B is cut off because of the low plate voltage of V5202 and the -105 volt power supply. A negative trigger applied to V5202 cuts it off and the positive-going plate drives the grid of V5203B into conduction. The negative swing of plate 5 of V5203B holds V5202 in cut-off for a time determined by the time constant of C5218, R5214, and R5215. This time can be adjusted by the Range Sweep Length Potentiometer, R5215.



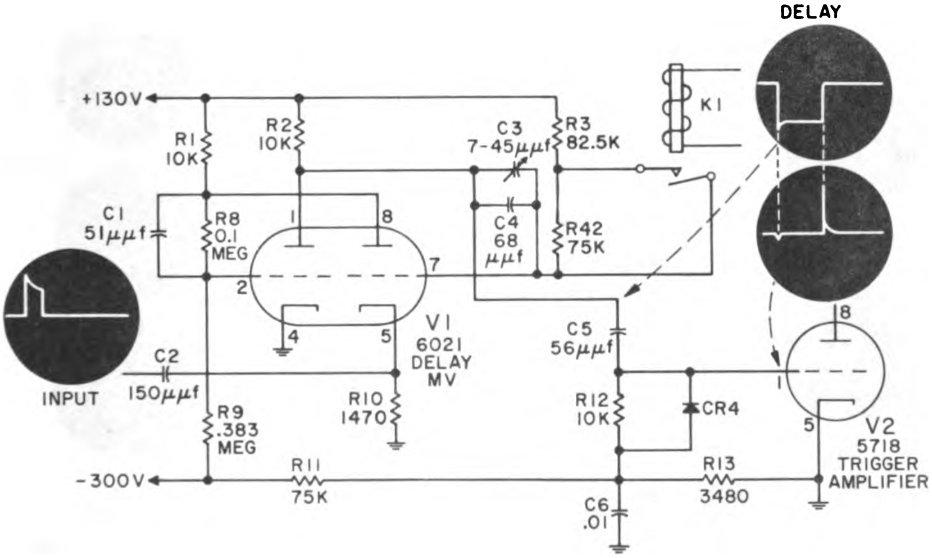
203. — Mark 35 Radar one-shot multivibrator circuit.

Applications (Continued)

One multivibrator application using the output of the multivibrator as a source of a controlled delay is found in Radar Set AN/SPG-50. This example is a one-shot multivibrator. The quiescent state of the tube is with the 1-2-4 section cut off by the bias from a voltage divider connected between the +130-volt and the -300 volt power supplies. The 5-7-8 section is conducting as grid 7 is connected through R42 and R3 to the +130-volt supply.



204. — Use of multivibrator in AN/SPG-50 Radar.



205. — AN/SPG-50 Radar delay multivibrator circuit.

The positive pulse of the differentiated video gate input is applied to cathode pin 5 of V1. This initiates the multivibrator action and one cycle of square waves is produced. The output square wave at plate 1 is differentiated by C5 and R12. The time delay obtained is the difference between the negative-going leading edge and the positive-going trailing edge of the square wave.

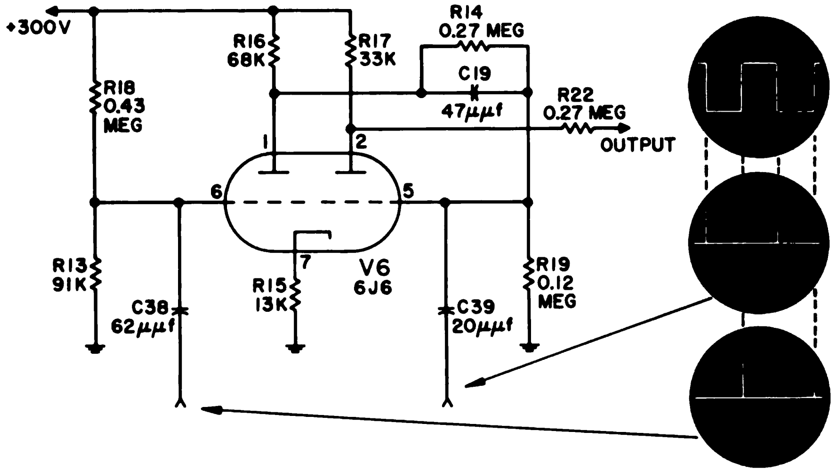
R3 and R42 are in series when K1 is released and provide a longer time delay. With K1 operated, R42 is shorted out and the negative portion of the square wave at plate 1 is shorter. C3, which is in parallel with C4, is variable and provides a further control of the duration of the negative portion of the square wave. C3 provides a fine adjustment of the delay, so that an exact time delay can be obtained.

Applications (Continued)

On these two pages is shown an application of a flip-flop (Eccles-Jordan) multivibrator. This circuit will be encountered in three fire control radar equipments. They are the Mark 25 Mod 3, AN/SPG-48, and AN/SPG-50. Its purpose is to provide an output square wave for use in the automatic frequency control (AFC) circuits.

Only the basic portion of this slightly modified flip-flop multivibrator circuit is shown on this page. The complete circuit is on the next page.

When voltage is first applied to the circuit, both grid 5 and grid 6 will be positive. Both sections of the tube will conduct. The difference in plate load resistors will result in a larger voltage drop at plate 1. This plate is directly coupled through R14 to grid 5 and the drop at the plate will reduce the positive voltage at this grid. Cathode voltage is increasing, and the drop in grid voltage and rise in cathode voltage soon drive section 2-5-7 to cut-off. When this section is cut off, the conduction in the 1-6-7 section soon stabilizes, and the first of two possible static conditions has been reached.



206. — Basic portion of flip-flop multivibrator circuit used in Mark 25, AN/SPG-48, and AN/SPG-50 Radars.

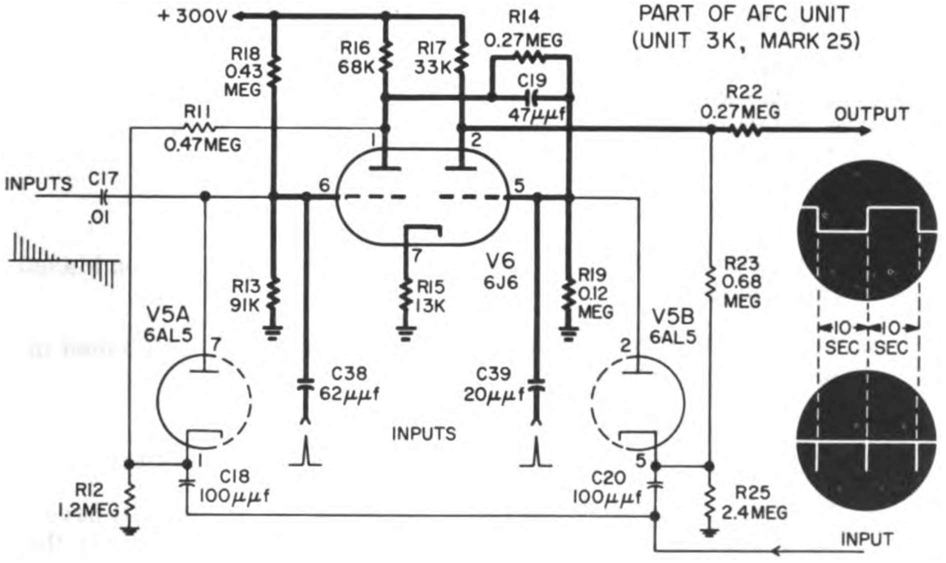
If a positive trigger is applied to the 1-6-7 section through C38, nothing happens since this section is already conducting. However, a positive trigger to the 2-5-7 section will cause it to conduct. Conduction in the 2-5-7 section will raise the voltage across the common cathode resistor and the 1-6-7 section will be cut off. The voltage at plate 1 rises to the B+ level and further increases conduction in the 2-5-7 section. Since the plate load resistor, R17, in the 2-5-7 section is about one-half that of the plate load resistor in the 1-6-7 section, more current will flow through the common cathode resistor when the 2-5-7 section is conducting than when the 1-6-7 section is conducting. The increased cathode voltage will hold the 1-6-7 section below cut-off and the multivibrator has "flipped" to its second static condition.

Now, if a positive trigger is applied through C38 to the 1-6-7 section, the multivibrator will be "flopped" back to its original state.

Applications (Continued)

The flip-flop multivibrator shown on the opposite page is further modified to permit the application of other signals. The complete circuit is shown below.

This circuit can also be triggered by a signal coupled across C17 to the control grid of the 1-6-7 section. This signal is the output of the discriminator circuit in the AFC unit. When the IF (Intermediate Frequency) is high, the signal across C17 will be positive; when the IF is low, the signal will be negative. When the 1-6-7 section of V6 is conducting and the signal applied to C17 is negative, the multivibrator will be "flopped." The output of V6 will then be sent to circuits which will bring the IF to the desired frequency. When the 1-6-7 section is cut off, a positive output from the discriminator coupled across C17 will "flip" V6. The output of V6 will be used to again bring the IF to the correct frequency.



207. — Complete flip-flop multivibrator circuit.

The output of V6 is also used to cause the AFC system to search for the proper IF. To provide enough time for the system to do this, a phantastron-type oscillator circuit is used which applies a negative pulse to C18 and C20 every ten seconds. This pulse is then coupled through one-half of V5 to one of the grids of V6. When plate 1 of V6 is conducting, plate 2 is cut off. Since pin 1 of V6 is low, the cathode (pin 1) of V5A is low, and because plate 2 of V6 is high, the cathode (pin 5) of V5B is high. The negative pulse is only large enough to bring the V5A section of the diode into conduction to trigger V6. Thus, one-half of V5 is a pulse selector and the other a pulse rejector with V6 in one of its quiescent conditions. For the other condition of V6, the two halves of V5 reverse their functions. There are three possible sources of triggers of V6. The input triggers through V5 are available at all times that the circuit is operating. Through the necessary switching in the external circuits the input through C17 is used as the triggers for V6 or the input through C38 or C39 is used as the triggers for the multivibrator.

MULTIVIBRATORS

Review

In this topic, you have studied the basic multivibrators and have worked with the two basic types in your chassis. You have also seen some of the variations of multivibrator circuits that you will encounter in fire control radar equipments.

Some of the primary things that you should have learned in this topic are listed below:

1. There are two basic types of multivibrators:

    a. Free-running
    b. Driven

2. The output of a multivibrator is a square wave.

3. There are a variety of names associated with driven multivibrators, such as:

    a. One-shot
    b. One-kick
    c. Start-stop
    d. Single-shot
    e. Monovibrator
    f. Flip-flop (Eccles-Jordan)

4. In practice, most driven multivibrators have one section biased into cut-off.

5. Coupling from one section to the other may be accomplished in the following manner:

    a. Plate-to-grid and plate-to-grid
    b. Plate-to-grid and through a common cathode resistor

6. In free-running multivibrators, the output waveform will have equal positive and negative portions if the time constants in the grid circuits are equal.

7. The output waveform will be unequal if the time constants in the grid circuits are unequal.

8. The frequency of a free-running multivibrator can be changed by varying the time constant in one grid circuit.

9. Frequency of a driven multivibrator is dependent upon the trigger frequency.

10. Multivibrators are used as the source of the Pulse Repetition Frequency (PRF), intensifier (unblank) voltages, range sweep voltages, pulses for counting circuits; as a means of introducing a desired delay; and for other purposes in fire control radar equipments.

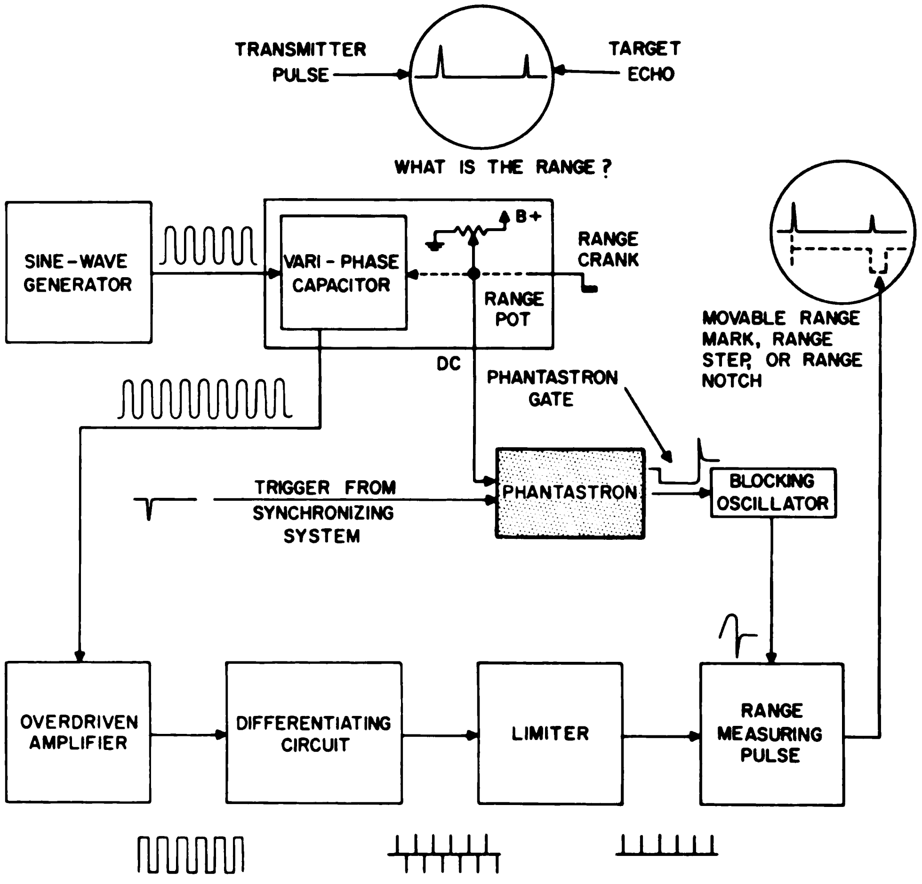
Notes

TOPIC 10: THE PHANTASTRON

General Purpose

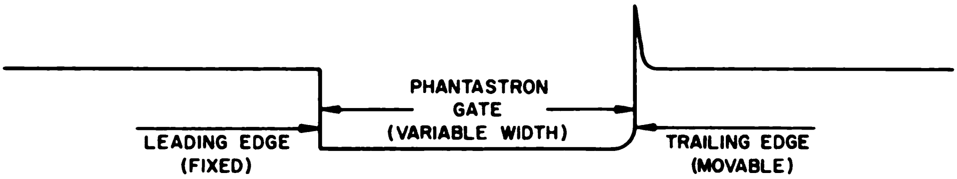
The phantastron is a special circuit found in the ranging system of several fire control radars. It has an output which is a square wave, and the duration of this output can be varied over the entire range limits of the radar in which it is used. The duration of the output in microseconds is very nearly equivalent to the range in yards that is read from the range dials of the radar.

The trailing edge of the output waveform is used in the following circuits to develop a pulse. This pulse then develops a signal which appears on the radar screen as either a range step, range mark, or range notch. Since the phantastron output is variable, then these signals are also variable and can be moved to coincide with target echoes. This movement is produced by changing the range handcrank which varies the phantastron output. If a set of dials are connected to the range crank, they will indicate the duration of the phantastron output. However, instead of indicating microseconds, they will be calibrated in yards of range.



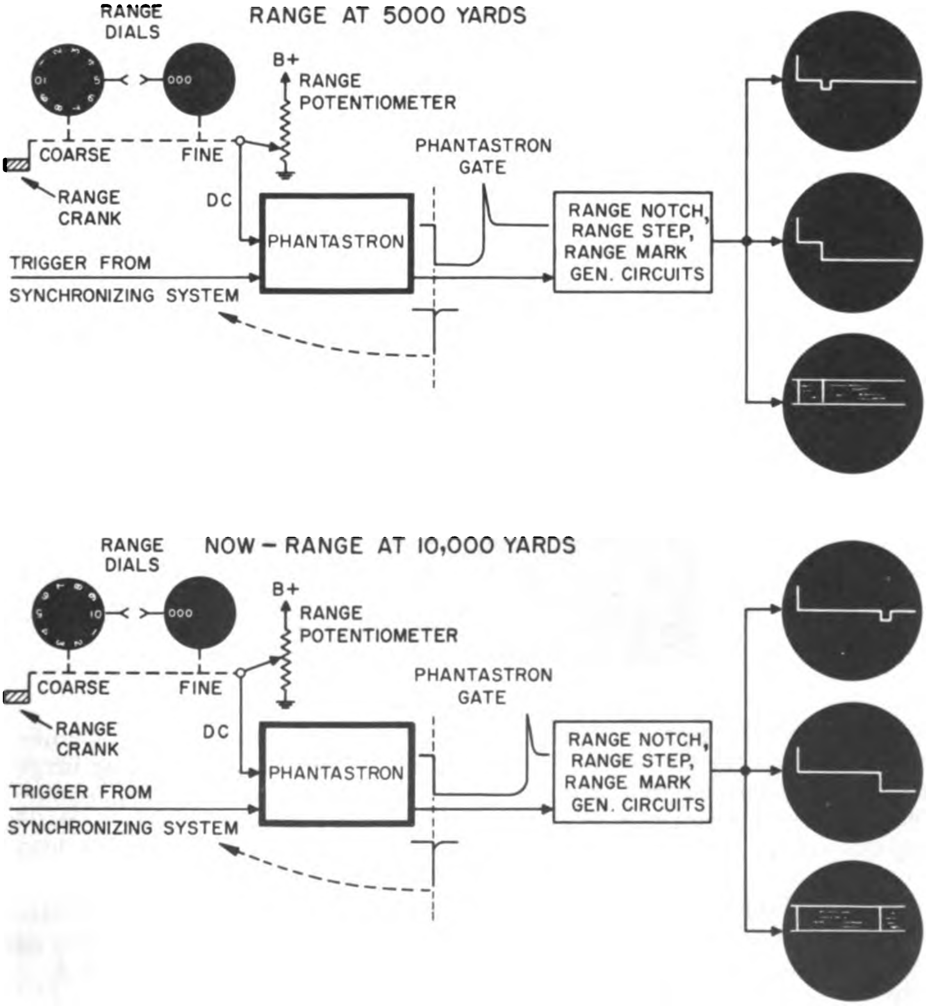
208. — The phantastron.

General Purpose (Continued)



209.—Phantastron gate waveform.

The output of the phantastron is a square wave. The negative portion of this wave is referred to as the phantastron gate. The duration of this gate may be easily changed. The leading (left-hand) edge of the gate has a fixed time relationship with the synchronizing pulses used in the radar equipment. The time of occurrence of the trailing (right-hand) edge of the gate may be changed. In this manner, the width of the gate is made variable.



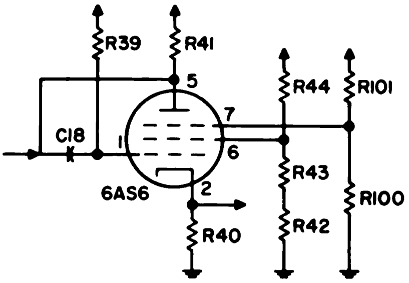
210.—Phantastron ranging waveforms.

THE PHANTASTRON

The Basic Phantastron

In a basic phantastron circuit, two voltage dividers are used to establish the potentials of the screen and suppressor grids of the tube. There is also a feedback circuit from the plate to the control grid. The control grid is returned to B+ through a large resistance. This, in turn, sets the grid near the cathode potential of the tube. One of the voltage dividers is selected to produce a high screen current. The combination of control grid current and the screen current establishes the cathode potential. However, the screen current is much larger than the control grid current and is the controlling factor. The other voltage divider is selected to establish the suppressor grid at a lower voltage than the cathode. This combination of potentials sets the quiescent condition of the circuit. Since the suppressor is at a less positive potential than the cathode, it blocks current flow to the plate, and all tube current is essentially in the screen circuit; thus, plate potential is high.

There is another factor utilized in the phantastron circuit. This is the fact that, at some high value of plate current, any further positive change in grid voltage will produce no further change in plate current. There is a minimum plate voltage that will be reached at which there will be no further increase in plate current This value of plate voltage produced by the plate current is sometimes referred to as "plate bottoming " voltage Since the tube characteristics are reasonably constant, the point at which the plate stops attracting additional electrons ("bottoms") is also constant.



KEYS TO PHANTASTRON OPERATION

1. SUPPRESSOR-TO-CATHODE VOLTAGE.
2. PLATE-TO-GRID FEEDBACK.
3. PLATE "BOTTOMING" VOLTAGE.

211.—Basic phantastron circuit.

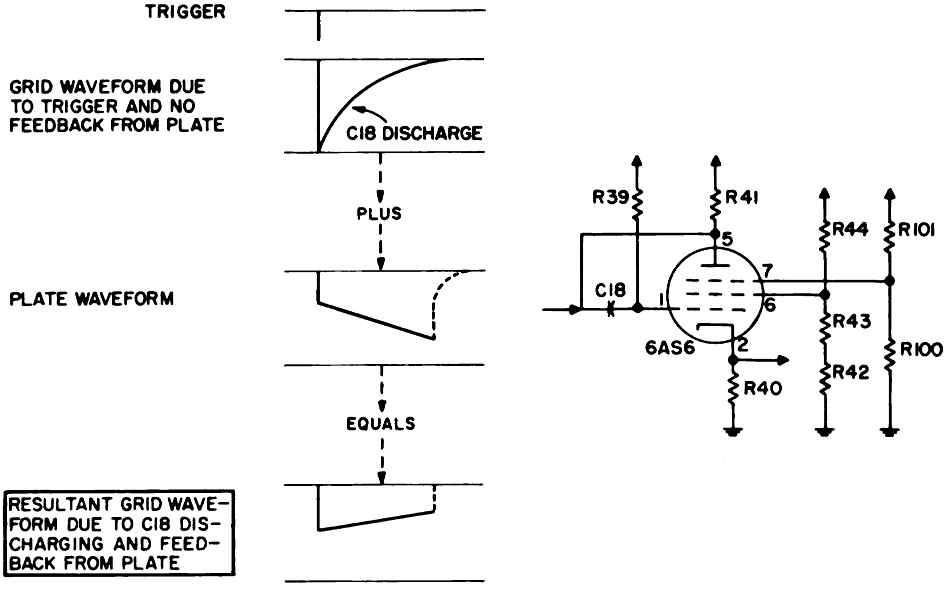
Let us now analyze the basic circuit operation. The circuit is quiescent; plate current cut off, and plate voltage at B+; screen drawing large current; cathode and grid nearly the same potential; and the suppressor negative, relative to the cathode. The charge across the grid capacitor is almost equal to B+.

Our problem now is to trigger the circuit so that the suppressor-to-cathode voltage will no longer prevent the flow of plate current. This can be done by the application of a positive trigger to the suppressor or a negative trigger to the control grid.

The Basic Phantastron (Continued)

Assume that a negative trigger is applied to the control grid. The circuit will start one cycle of operation. The negative trigger is coupled through C18. This drives the control grid in a negative direction and reduces tube current. The cathode potential drops so that the suppressor-to-cathode potential no longer blocks plate current. As plate current starts flowing through R41, the drop in plate voltage is coupled by capacitor C18 to the control grid.

Now let us see what is taking place in the grid circuit of the phantastron. Initially, a negative trigger coupled through C18 drove the grid negative. The capacitor will start to discharge exponentially across R39; the grid begins to rise along the exponential curve. However, as you can see, the plate is coupled back to the control grid through the capacitor. Since the plate voltage has dropped, the negative-going plate is attempting to drive the control grid negative. At this same time, the capacitor is discharging exponentially. The sum voltage produced by these two factors is a very linear rise of the control grid potential. Circuit components are selected so that the discharge of the capacitor is slightly greater than the drop in plate voltage.

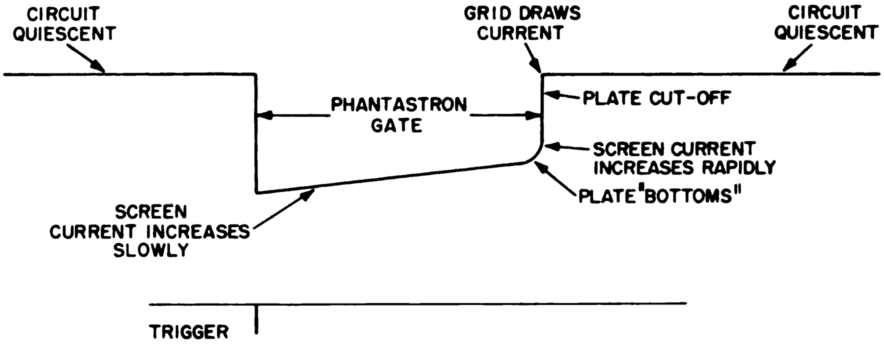

TRIGGER
GRID WAVEFORM DUE TO TRIGGER AND NO FEEDBACK FROM PLATE
C18 DISCHARGE
PLUS
PLATE WAVEFORM
EQUALS
RESULTANT GRID WAVEFORM DUE TO C18 DISCHARGING AND FEEDBACK FROM PLATE
R39
R41
R44
R101
5
7
C18
1
6
6AS6
2
R43
R42
R40
R100

212.—Triggered control grid.

Since the control grid is continually rising, plate current continuously increases; thus, plate voltage continually decreases. This drop in plate voltage continues until any further positive change in control grid voltage produces no further change in plate current. The tube has reached plate current saturation; the plate "bottoms."

The Basic Phantastron (Continued)

When the plate "bottoms," another switching action occurs. When the circuit was triggered, screen current decreased because of the reduced tube current. Then, as plate current increased, screen current started to increase slowly. Now, when the plate potential reaches its minimum point, the screen starts drawing more current. This action is aided because there is no further change in the feedback voltage from plate to grid, so the grid potential rises at a faster rate, allowing more tube current to flow. This increase in tube current causes the cathode potential to rise. It rises until the suppressor-to-cathode potential shuts off plate current. At this time, plate voltage starts rising exponentially toward B+. The grid then goes positive, the cathode in turn rises with the grid, and then both grid and cathode return to their normal pre-trigger value as the grid starts drawing current.



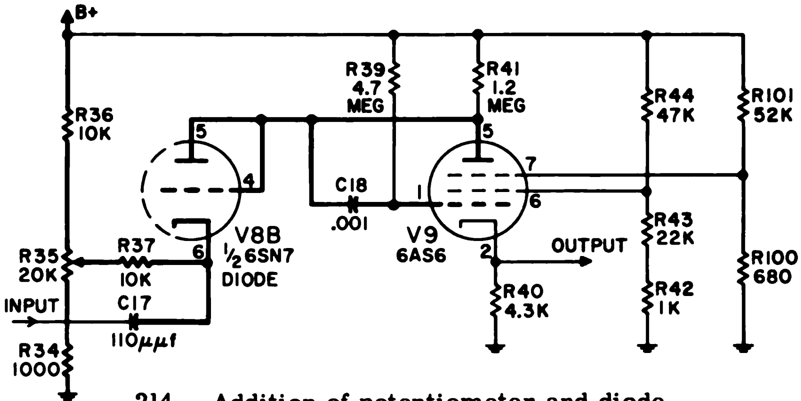
213.—Phantastron gate cathode waveform.

The circuit has now reached its pre-trigger condition, quiescent. A negative square wave has been produced across the cathode resistor. The duration of this negative square wave was determined by the time required for plate voltage to fall from some high value to the point at which it "bottomed." This time is a function of the R-C time of C18 and R39, and the rate of change of plate current in the phantastron tube.

In the foregoing discussion, you have probably noted that none of the components were variable; thus, if another trigger were applied to this basic circuit, the output waveform would be of the same duration. To obtain a variable delay, we could change the R-C network, C18-R39. However, an easier solution is to vary the initial plate voltage on the tube. We know that the characteristic of this tube is that it will always reach the same low plate voltage at which any further change in the grid will produce no change in the plate. Then, by varying plate voltage, we can vary the duration of the output square wave. If the initial plate voltage is low, it will take a short time to reach the point at which the plate "bottoms;" and the negative square wave will be short. If we start with a high plate voltage, the square wave output will be long since it will take longer for the plate to "bottom."

Additions to the Basic Phantastron

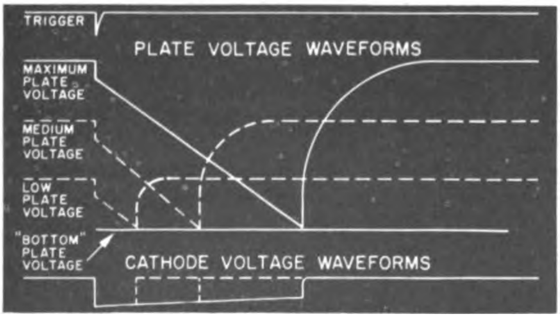
The duration of the phantastron gate is made variable by applying a d-c voltage to the plate from the arm of a potentiometer. This potentiometer can select a voltage within the range of near zero to near the B+ voltage. A diode is inserted in series with the arm of the potentiometer and the plate of the phantastron. With the circuit in its quiescent condition, the voltage at the plate will be essentially the same as the voltage at the arm of the potentiometer. The addition of the diode and the potentiometer to the basic phantastron circuit permits the width of the phantastron gate to be controlled.



214. —Addition of potentiometer and diode.

The diode serves to disconnect the plate circuit from the potentiometer after a trigger pulse is received. The slow linear drop in plate voltage, after application of a trigger, is isolated from the potentiometer by the diode. At the termination of the phantastron gate, the voltage at the plate of the tube will return to the voltage at the arm of the potentiometer at an exponential rate.

In the basic phantastron circuit, the plate voltage dropped sharply from B+, when the trigger was applied, and then began a slow linear drop. This linear drop continued until the plate voltage "bottomed" at some low plate voltage. This plate "bottoming" voltage is a constant for a phantastron circuit. This means that if a lower than B+ voltage is applied to the plate, the slow linear drop will reach the plate "bottoming" potential in less time and the gate will be of less duration.

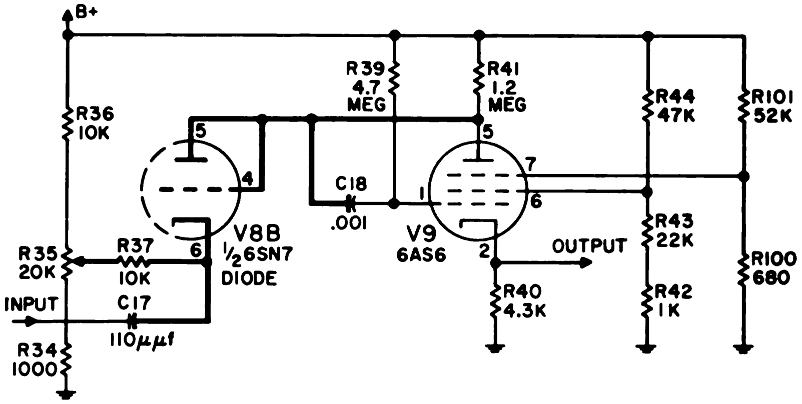


215. —Basic circuit plate voltage drop.

Additions to the Basic Phantastron (Continued)

The potentiometer and diode establish the charge on C18 when the circuit is in its quiescent state. Plate "bottoming" is reached when C18 has discharged to some low voltage level. This voltage level is constant. If, with the circuit in the static condition, the charge on C18 is increased, a longer time after application of the trigger will be required for the capacitor to discharge to the low level at which the gate is terminated.

A linear potentiometer is used in the phantastron circuit. Rotation of the arm of the potentiometer provides a linear change in plate voltage from near zero to near the B+ voltage level. The width of the gate is directly proportional to the voltage applied to the plate, so the width of the gate may be varied from a few microseconds to several hundred microseconds.



216. —Addition of linear potentiometer.

Measurement of radar range, using a phantastron circuit, is accomplished by connecting the arm of the potentiometer and the range dials through gears to a handcrank. Turning the handcrank in a direction that will increase the plate voltage on the phantastron will increase the width of the gate, and will increase the range dial reading by a corresponding amount. In order to change the range from a remote position, an electric motor and a servo system are used. The motor provides a means of rapidly changing the range. The servo system makes possible slower changes in range for placing the range exactly on target, and for keeping the range on target while tracking automatically in range.

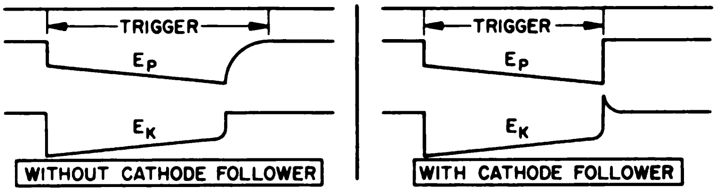
You have already learned that 1000 yards of radar range is equal to 6.1 microseconds in time. In radar range units, a definite zero time is established, and the delay from this zero time is the radar range. A further delay of 6.1 microseconds from zero time will indicate a range of 1000 yards. The delay may be varied from zero time by any fraction or multiple of 6.1 microseconds up to the maximum delay obtainable in the phantastron circuit. The maximum delay is the maximum gate width, and is determined by the constants in the tube and its circuits and the applied voltage.

Additions to the Basic Phantastron (Continued)

You have seen on the preceding pages that when the plate reaches saturation ("bottoms"), it does not immediately rise to its initial voltage because of the R-C time constants of C18 and R41.

Because of the exponential rise of the plate, it will not reach the potential at the arm of the range delay potentiometer until some time after the phantastron gate has been terminated. This exponential rise means that the repetition frequency of the trigger would have to be slower. This is not desirable in fire control radars.

To eliminate this difficulty, we must provide some means to cause C18 to charge more rapidly at the time that plate current is shut off. This action is obtained by the use of a cathode follower connected in the feedback circuit from the plate of the phantastron, V9, to C18. The cathode follower also serves to connect the arm of the range delay potentiometer, R35, through the diode, to C18.

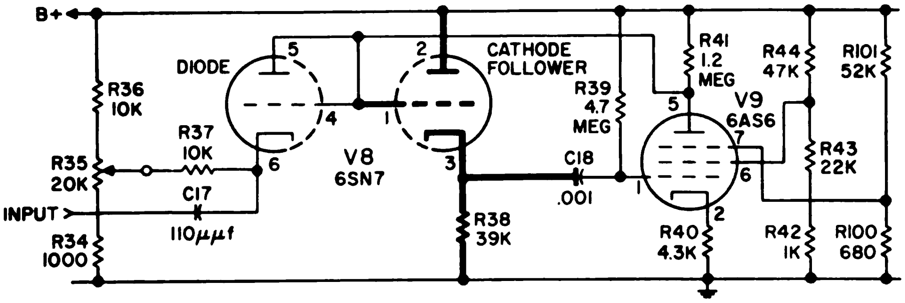


WITHOUT CATHODE FOLLOWER

WITH CATHODE FOLLOWER

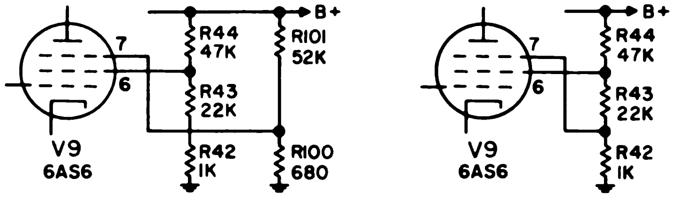
217.—Feedback circuit waveforms.

Note that when a trigger is applied to the circuit, it is coupled through the diode to the grid of the cathode follower. It then appears in the cathode and is coupled through C18 to initiate a cycle of operation in the phantastron circuit. As plate voltage on the phantastron (V9) drops, this drop is coupled through the 1-2-3 section of V8 to C18. This action continues until the plate current of V9 stops increasing. At this time, the plate voltage of V9 starts rising; this positive-going voltage is applied on the grid of the cathode follower. This drives the grid of V9 sharply positive and terminates the phantastron gate. Since C18 is permitted to charge rapidly through the cathode follower, the exponential rise of the plate is eliminated and it returns to the level set by the range potentiometer. This permits the trigger frequency to be increased, and also accounts for the peak on the trailing edge of the phantastron gate.



218.—Addition of the cathode follower.

Additions to the Basic Phantastron (Continued)

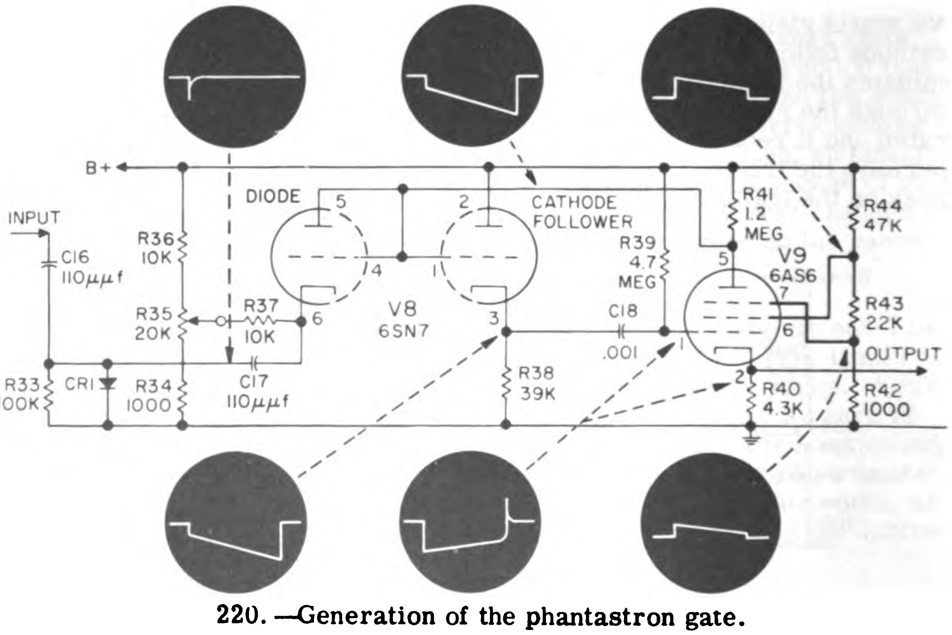


219. —Single screen and suppressor grid voltage supply.

Another refinement in the basic phantastron circuit is added to the phantastron in the chassis. Instead of two separate voltage dividers being used to supply screen grid and suppressor grid voltages, there is one voltage divider used to perform both functions. Resistors have been chosen that will give the correct potentials for both elements when the circuit is in its quiescent state. This arrangement insures more positive circuit action at the beginning and end of the phantastron gate. When the trigger is applied, screen current through R44 will be reduced. This results in an increased suppressor grid voltage from the voltage divider and reduces the suppressor-to-cathode bias. During the switching action that terminates in the end of the gate, the increased screen current through R44 reduces the suppressor voltage, and the increasing cathode voltage rapidly brings the suppressor-to-cathode bias to the plate current cut-off point.

Your Phantastron Circuit

The schematic of the phantastron on this page is of the one in the chassis. The input trigger is obtained from plate pin 2 of V7. The negative square wave is differentiated across C16 and R33. The purpose of CR1 is to limit the positive portion of the differentiated square wave. The negative trigger is then coupled through C17 into the phantastron circuit.



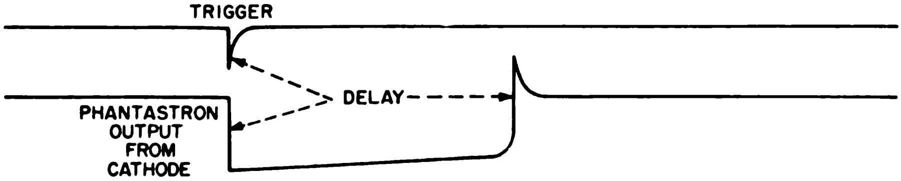
220. —Generation of the phantastron gate.

Your Phantastron Circuit (Continued)

Let us now review the circuit operation from the quiescent condition through the generation of the gate and return to the quiescent condition.

In the quiescent condition, there is no plate current flowing through V9. This is due to the suppressor-to-cathode bias being below the plate current cut-off level. The screen grid is drawing current. The voltage across the cathode resistor is the result of this screen current and a small amount of control grid current. The control grid current maintains this grid near cathode potential. The voltage at the plate of V9 is very near that at the arm of potentiometer R35, as the drop across R37 and the diode is small compared to that across R41. Grid 1 of V8 is at the potential of plate pin 5 of V9 and will raise the potential of cathode 3 of V8 to nearly this same potential. This establishes the charge across C18. It will have on its right-hand plate essentially the potential of cathode pin 2 of V9 and on its left-hand plate will be the potential of plate pin 5 of V9.

A sharp negative pulse coupled through C17 initiates phantastron action. This negative trigger is coupled through the diode, the cathode follower, and C18 to grid 1 of V9. Tube current is reduced sharply. The drop in cathode voltage reduces the suppressor-to-cathode bias to a level that permits plate current to start flowing. The resulting drop across R41 is coupled through the cathode follower to C18. This negative feedback slows the rise in control grid voltage. Plate, screen, and cathode currents will increase slowly as the grid voltage rises. The large plate load resistor reduces plate voltage and a point is reached at which a further increase in control grid voltage will not increase plate current. Without the negative feedback that was slowing the rise in grid voltage, the grid voltage will increase at a faster rate. The screen grid current increases and raises the cathode-to-suppressor bias to the plate current cut-off level. Plate voltage returns to the potential on the arm of R35. C18 charges rapidly through the cathode follower, sharply increasing control grid voltage. The resulting increase in screen current produces the sharp positive peak on the cathode waveform at the end of the gate. The control grid draws current and reduces its potential to near that on the cathode of V9. The charge across C18 has returned to its original amount. The cycle has been completed and the circuit is now in readiness for the next trigger.



221. —Phantastron gate control.

A phantastron gate has been produced and the width of the gate may be changed by rotation of the arm of potentiometer R35. The delay between the trigger applied to the circuit and the end of the gate may be controlled.

Experiment—Basic Phantastron Test Setup

You are now going to modify the phantastron circuit in your chassis to a basic phantastron circuit.

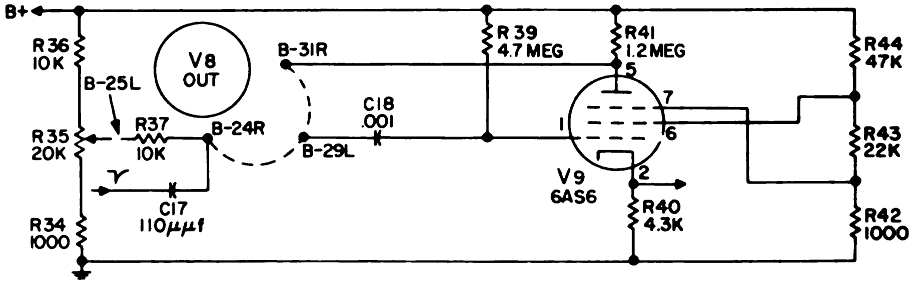
You will then read and record the voltages with the circuit quiescent, and also while it is operating. You will observe and record the waveforms in the basic phantastron, and in the following experiments will modify the chassis to a complete and practical type of phantastron circuit as actually used in fire control radars.

For this experiment, you will require an oscilloscope, multimeter, and a 6AS6 (V9) vacuum tube. You will also be required to record the waveforms you see on the 'scope.

1. Modify the chassis.

   a. Unsolder B+ lead from plate pin 2 of V8 socket.
   b. Disconnect R37 at B-25L.
   c. Disconnect R38 at B-28L.
   d. Connect jumper from B-29L to B-31R.
   e. Connect jumper from B-24R to B-29L.
   f. Insure that V8 is REMOVED.

Your circuit should now be wired to agree with the schematic shown below.



222. —Basic phantastron circuit.

2. With the oscilloscope, make sure that the input trigger to the phantastron is available.

You are now ready to proceed with your experiment with the basic phantastron circuit.

1. With the voltmeter, read and record the voltage readings between ground and the following points on V9:

   a. Plate pin 5
   b. Grid pin 1
   c. Cathode pin 2
   d. Screen grid pin 6
   e. Suppressor grid pin 7

2. Remove the jumper from B-24R to B-29L and repeat step 1 above. Compare these readings with those taken while the circuit was operating.

3. Replace the jumper between B-24R and B-29L.

Experiment—Basic Phantastron Test Setup (Continued)

You are now going to observe the waveforms in the basic phantastron circuit. Then you will observe the waveforms with the diode added to the circuit.

1. Set 'scope control to External Sync and connect plate pin 5 of V7 to the External Sync input of the 'scope.

2. Connect 'scope probe to plate pin 5 of V9. Note and record the waveform. Notice especially the exponential rise of the plate voltage.

3. Connect 'scope probe to grid pin 1 of V9; note and record the waveform.

4. Connect 'scope probe to cathode pin 2 of V9; note and record waveform.

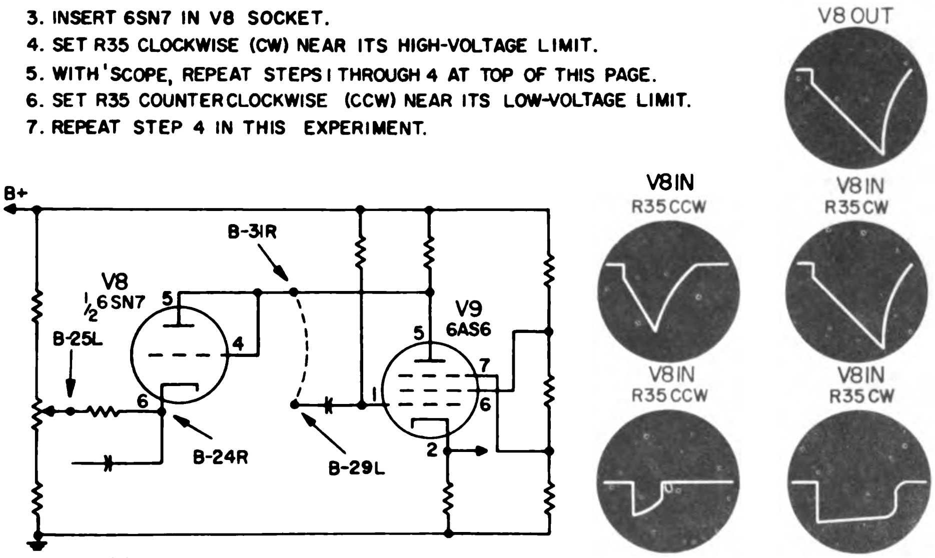
5. De-energize power to the chassis.

Experiment—Basic Phantastron with Diode

Notice in your basic circuit that there is no means provided to vary the duration of the phantastron gate. A variable delay is required and it is provided by the action of the potentiometer, R35. However, it cannot be connected directly into the circuit because it would change the value of the plate load resistor of V9. To prevent this is the purpose of the diode.

You will now modify your chassis to permit variations of R35 to affect the output, and will insert the diode to prevent the resistance of R35 and R36 from being felt in the plate circuit of V9.

1. REMOVE THE JUMPER BETWEEN B-24R AND B-29L.
2. CONNECT R37 AT B-25L.
3. INSERT 6SN7 IN V8 SOCKET.
4. SET R35 CLOCKWISE (CW) NEAR ITS HIGH-VOLTAGE LIMIT.
5. WITH 'SCOPE, REPEAT STEPS 1 THROUGH 4 AT TOP OF THIS PAGE.
6. SET R35 COUNTERCLOCKWISE (CCW) NEAR ITS LOW-VOLTAGE LIMIT.
7. REPEAT STEP 4 IN THIS EXPERIMENT.



223.—Variable delay of phantastron gate—test setup.

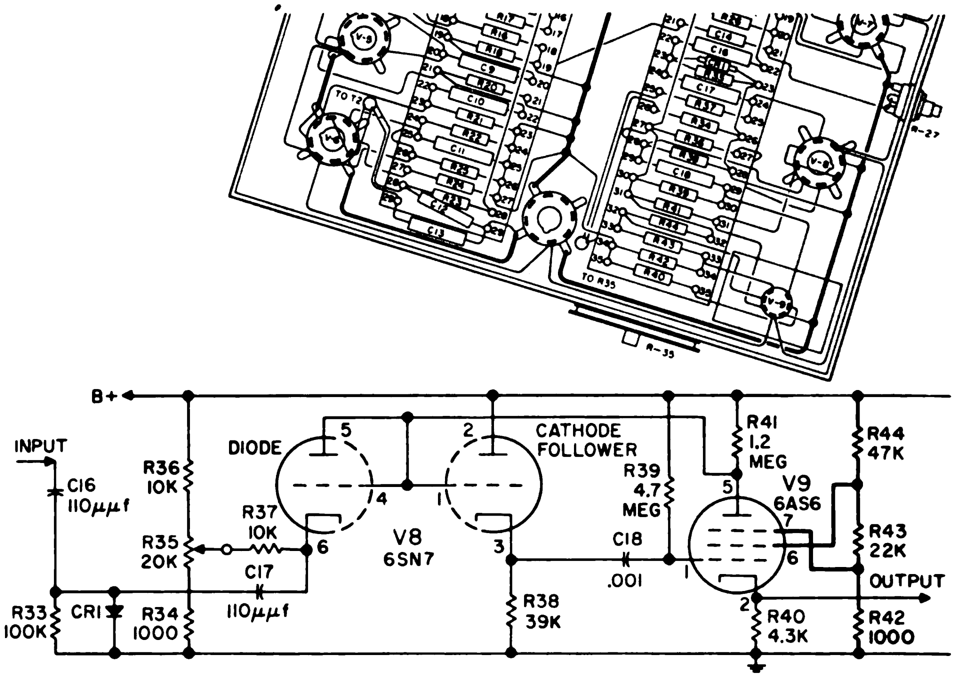
Experiment—Phantastron with Cathode Follower—Waveforms

You are now going to modify your basic phantastron circuit to include a cathode follower. You will compare these waveforms with those you obtained in the previous experiment.

To modify your chassis, proceed as follows:

1. De-energize the chassis.
2. Remove jumper between B-29L and B-31R.
3. Reconnect R38 to B-28L.
4. Resolder B+ lead to plate pin 2 of V8 socket.
5. Insert V8 (6SN7).

Your chassis should be wired in accordance with the schematic shown below.



224.—Cathode follower—test setup.

1. Make sure that the multivibrator is synchronized with the output of the Wien bridge oscillator.

2. Set 'scope control to External Sync and connect plate pin 5 of V7 to the External Sync input of the 'scope.

3. Set R35 near its full clockwise position (high-voltage end).

4. Connect 'scope probe to pin 6 of V8 and note presence of a negative trigger.

Experiment—Phantastron with Cathode Follower—Waveforms (Continued)

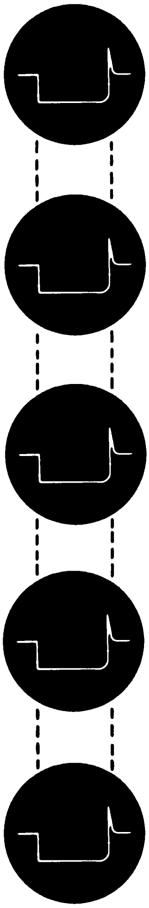
5. Connect 'scope probe to grid pin 1 of V9 and note the waveform.

6. Connect 'scope probe to cathode pin 2 of V9; note that the waveform is identical to that on the grid.

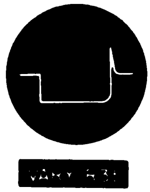
7. Connect 'scope to plate pin 5 of V9; note that the plate voltage drops with the application of the trigger and then continues to drop at a very linear rate as plate current increases. Notice also that when the plate reaches its lowest point ("bottoms") it very quickly returns to its initial potential. This is due to the fast charge of C18 through V8. Note also that the plate no longer rises exponentially.

8. Connect 'scope probe to the screen, pin 6, of V9; note that the voltage decreases from the instant the trigger is applied.

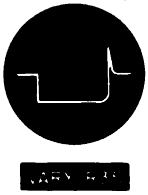
9. Connect 'scope probe to the suppressor, pin 7, of V9; note that the waveform is the same as at the screen but of smaller amplitude.



10. With the 'scope probe at the plate of V9, vary the setting of R35. Notice that as R35 is turned to the low-voltage end, the trailing edge of the waveform moves to the left. This indicates that the plate starts at a lower plate voltage and, therefore, requires less time to "bottom."



11. Place 'scope probe on cathode pin 2 of V9. Vary R35 from its low-voltage setting and note that the trailing edge of the gate moves to the right. This indicates an increase in the delay from the trigger.



THE PHANTASTRON

Experiment—Trouble Shooting

Trouble shooting in the phantastron circuit is no different than the trouble-shooting procedures you should have been practicing in the previous circuits that you have studied. Signal tracing, tube replacement, and voltage and resistance measurements remain as the logical steps in trouble shooting the phantastron circuit.

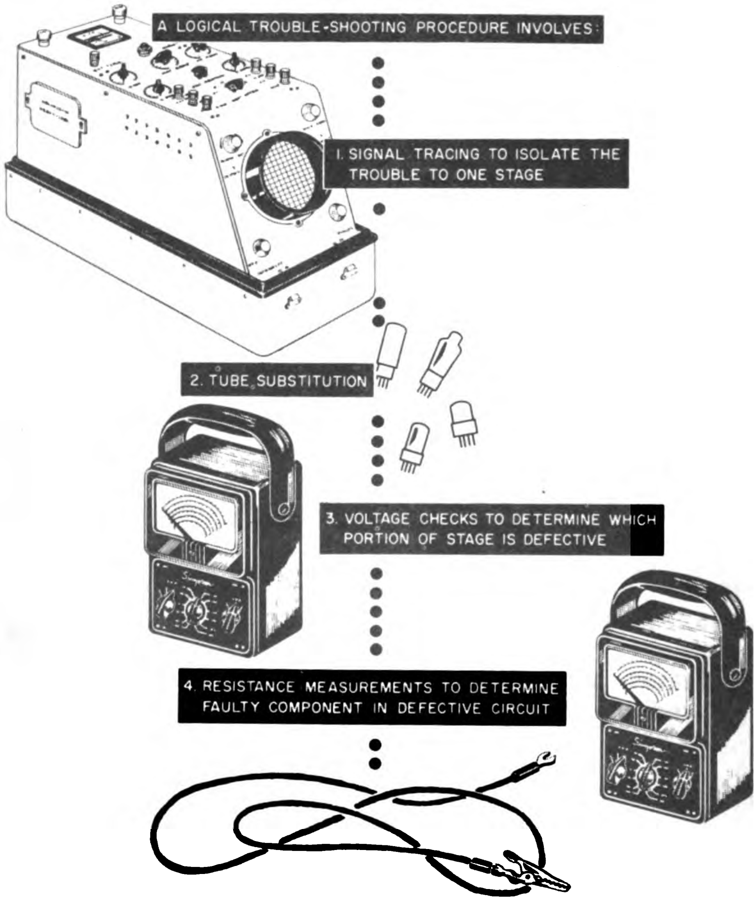
Below are some suggested casualties you might experiment with, and note the effects on the operation and the waveforms in the phantastron circuit.

1. Open R37.

2. Open filament circuit in V8 (check with your instructor first).

3. Open circuit from plate pin 5 of V9 to V8.

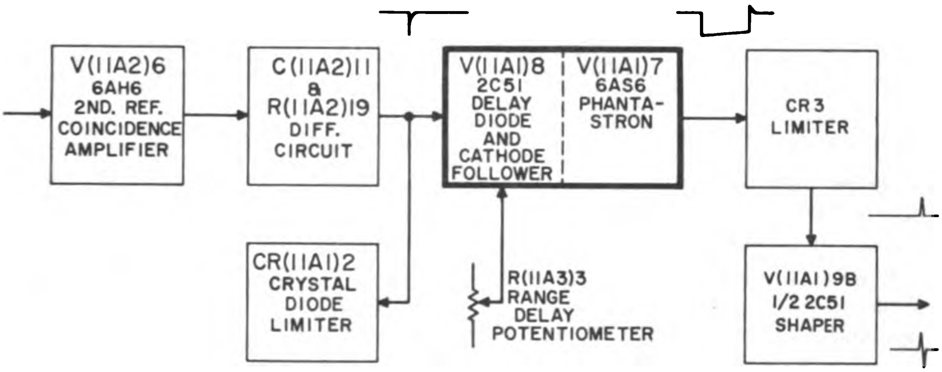
You and your partner will now insert approved troubles into each other's circuits. You will then service the circuits, using the same logical trouble-shooting procedure previously used.


A LOGICAL TROUBLE-SHOOTING PROCEDURE INVOLVES:
1. SIGNAL TRACING TO ISOLATE THE TROUBLE TO ONE STAGE
2. TUBE SUBSTITUTION
3. VOLTAGE CHECKS TO DETERMINE WHICH PORTION OF STAGE IS DEFECTIVE
4. RESISTANCE MEASUREMENTS TO DETERMINE FAULTY COMPONENT IN DEFECTIVE CIRCUIT

225. —Phantastron—trouble shooting.

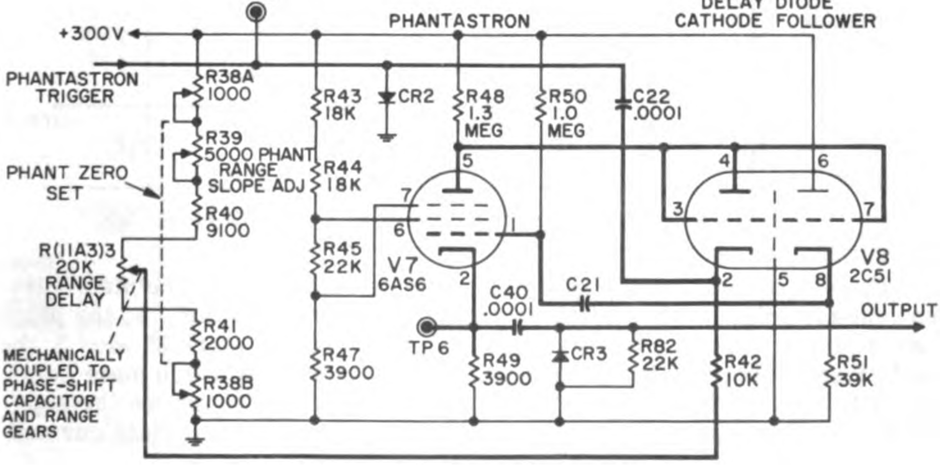
Applications

The first example of the use of the phantastron circuit in the ranging circuits of fire control radar equipments is from Radar Equipment Mark 25 Mod 3. The pulse to trigger the phantastron is from the output of a coincidence amplifier in the Synchronizing System. Since this pulse is also used to trigger a blocking oscillator, the waveform is that of the blocking oscillator. It is necessary to differentiate the waveform and to limit the positive portion so that a sharp negative trigger is applied to the phantastron circuit.



226.—Use of phantastron in Mark 25 Radar.

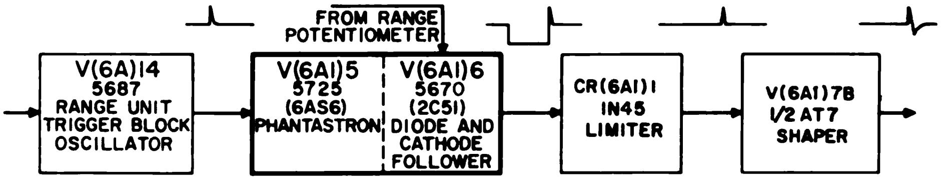
The circuit and the one in your chassis are very similar. There are slight differences in the location of components in the schematic. The diode and the cathode follower are to the right. You will also notice that there are potentiometers in series with the range delay potentiometer. However, the operation of the two circuits is identical. The additional potentiometers provide for fine adjustment of the range slope at the arm of R(11A3)3, and make it possible to obtain the desired slope as the arm of the potentiometer is rotated.



227.—Phantastron circuit in Mark 25 Radar.

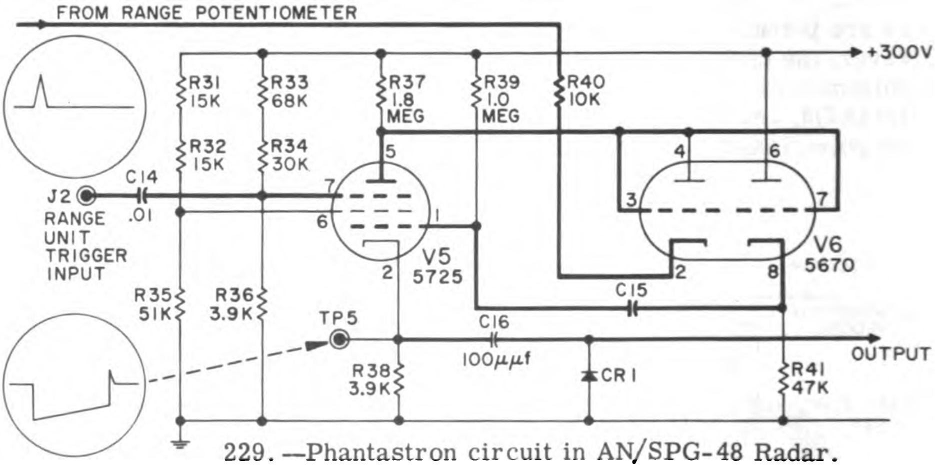
Applications (Continued)

The phantastron is used in the ranging circuits of Radar Set AN/SPG-48. Component arrangements and circuit components are very similar to the phantastron in Radar Equipment Mark 25 Mod 3. There is one major difference in that a positive pulse from the preceding blocking oscillator is used as the trigger. The phantastron output is applied to the grid of the shaper tube. The output of the shaper triggers the first range gate blocking oscillator which generates a positive gating voltage of several microseconds duration. The leading edge of the gating voltage is coincident with the trailing edge of the phantastron gate.



228.—Use of phantastron in AN/SPG-48 Radar.

The major difference in this phantastron from others that you have studied is the use of the positive trigger. The trigger is applied to the suppressor grid pin 7 of V5. This raises the suppressor-to-cathode voltage above the plate current cut-off point. Plate current then starts to flow and the circuit action from this point is identical to that in the other examples of the phantastron.

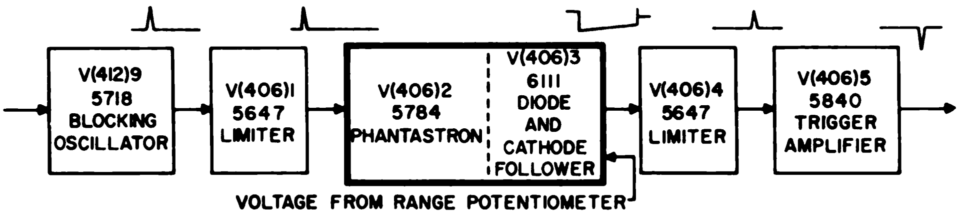


229.—Phantastron circuit in AN/SPG-48 Radar.

The suppressor-to-cathode voltage being raised above the plate current cut-off point is what initiates phantastron circuit action. In the phantastron in the chassis and the one in Radar Equipment Mark 25 Mod 3, the input trigger reduces the cathode voltage to the point at which plate current will flow. In Radar Set AN/SPG-48, the positive trigger on the suppressor grid raises the suppressor voltage to the point that plate current will flow. Either reducing cathode voltage or increasing the suppressor voltage will permit plate current to flow, and start the phantastron circuit action.

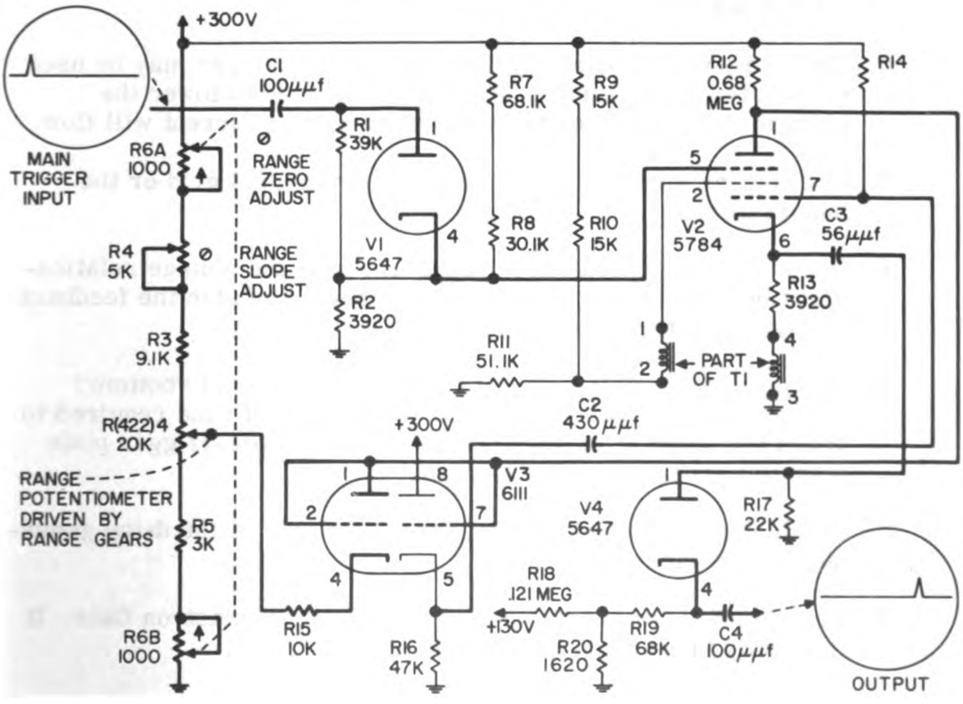
Applications (Continued)

The phantastron in the ranging circuits of Radar Set AN/SPG-50 is very similar to the one in Radar Set AN/SPG-48. A positive pulse from the blocking oscillator starts the generation of the delay. The trailing edge of the gate, a positive-going voltage, is applied through the diode as the trigger to the trigger amplifier.



230. —Use of phantastron in AN/SPG-50 Radar.

The positive main trigger input to the diode develops a positive pulse across R2. This raises the suppressor-to-cathode voltage above the plate current cut-off point. Plate current starts to flow and the drop in plate voltage is coupled through the feedback circuit to the grid of V2. The plate current through the 3-4 winding of T1 and the transformer coupling to the 1-2 winding reduce the screen grid voltage. The reduced control grid voltage, resulting from the plate voltage drop, and the lowered screen grid voltage reduce the total tube current, and produce the negative-going leading edge of the phantastron gate. From this point, circuit action is identical to that in the other examples that were given.



231. —Phantastron circuit in AN/SPG-50 Radar.

THE PHANTASTRON

Review

In this topic, you have studied the phantastron circuit and have followed its development from a basic type to those used in the ranging systems of fire control radar equipments.

The principal points that you should have learned are listed below.

1. It is a circuit which introduces a very linear delay. Because of its linearity, it is useful as a range measuring circuit.

2. The circuit usually consists of a variable potentiometer which provides a d-c voltage that determines the amount of delay the circuit will produce.

3. It also includes a diode that permits the voltage variations from the arm of the potentiometer to be applied to the grid capacitor and the plate of the phantastron, while it isolates the low resistance of the potentiometer from the high resistance of the plate circuit.

4. A cathode follower is also employed to provide a fast charge path for the grid capacitor and thus prevents any exponential rise of the plate during the termination of the gate. This allows the circuit to be triggered at a faster frequency because the plate is rapidly returned to normal.

5. The cathode follower also permits the voltage from the diode and the feedback voltage from the plate of the phantastron to be coupled to the grid.

6. Either a positive or a negative phantastron trigger may be used to initiate circuit action. The trigger is used to lower the cathode-to-suppressor potential so that plate current will flow.

7. The trigger may be applied either to the control grid or the suppressor.

8. Proper circuit operation is dependent upon the voltage relationships between the suppressor and cathode, and also the feedback voltage from the plate to grid.

9. The peculiarity of the circuit is that the tube must "bottom" (reach plate current saturation). The length of time required to reach this point is dependent upon the initial pre-trigger plate potential set by the potentiometer.

10. The higher the initial voltage, the longer will be the delay generated by the circuit.

11. The output of the phantastron is called the Phantastron Gate. It is usually taken from the cathode circuit.

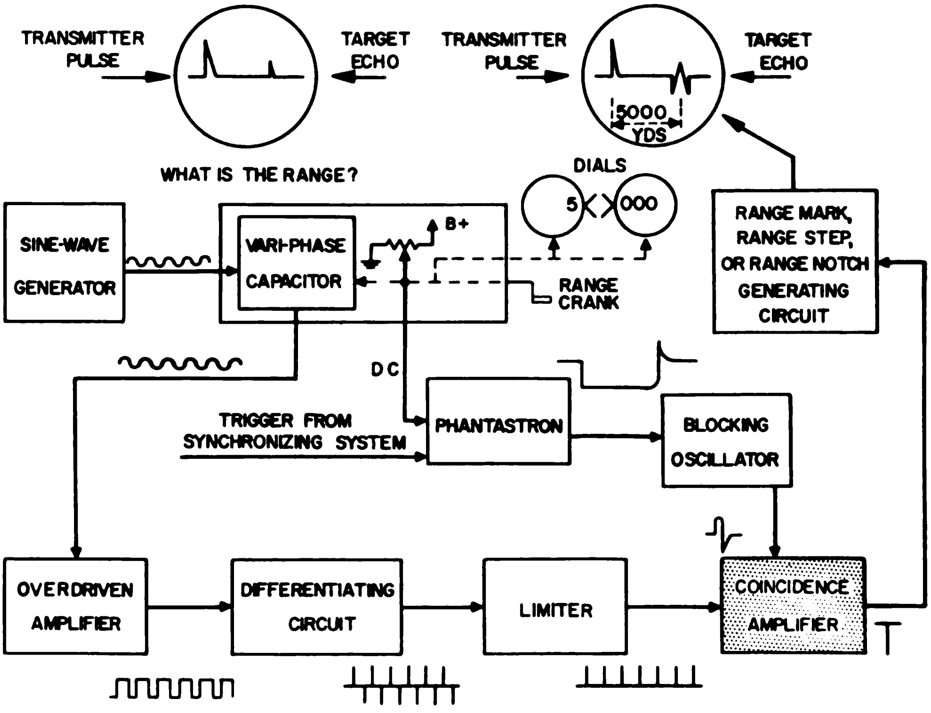
Notes

TOPIC 11: THE COINCIDENCE AMPLIFIER

General Purposes

Another circuit that is coming into widespread use in fire control radar equipments is the coincidence amplifier. This circuit requires the input of two signals and coincidence of these two signals is necessary before there is an output from the circuit. One input signal is a gating voltage of a few microseconds duration with a pulse repetition frequency that is the same as the PRF of the radar equipment. The other input signal is normally sharp pulses occurring at a much higher repetition frequency. One of these sharp pulses that occurs during the gating voltage will produce a sharp pulse in the output circuit of the coincidence amplifier. The output pulse will have the same repetition frequency as the PRF of the radar equipment.

The coincidence amplifier is used in the synchronizing and ranging circuits of fire control radar equipments. Its purpose is to establish very accurate delays. The delays obtained may be in multiples of the time interval between two successive timing pulses by the use of a series of coincidence amplifiers.

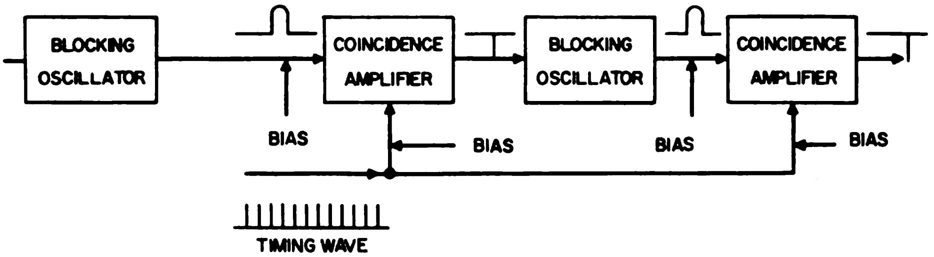


232. —Coincidence amplifier.

The sharp positive pulses that are applied to the coincidence amplifier occur at a frequency determined by the sine-wave generator. The sine-wave output of the sine-wave generator is shaped into a square wave by an overdriven amplifier. The square wave is then differentiated, giving sharp positive and negative pulses. Only the positive pulses are coupled through the limiter circuit to the coincidence amplifier. These pulses are referred to as timing pulses.

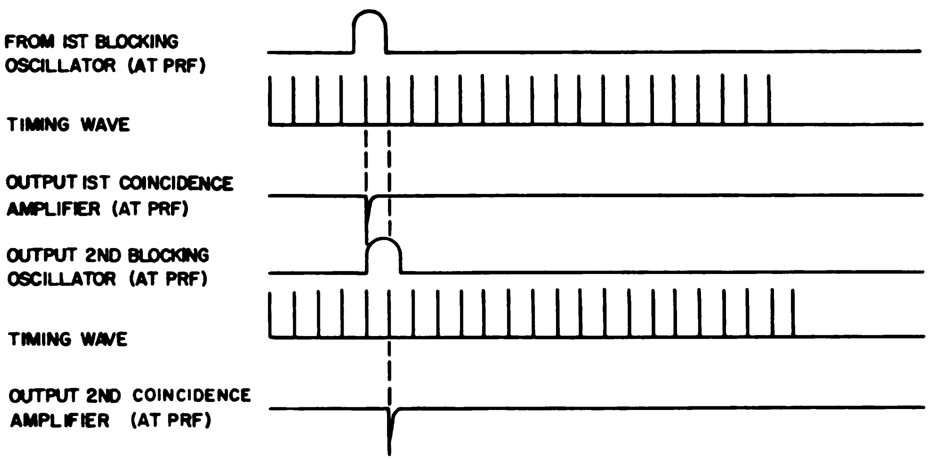
General Purposes (Continued)

The blocking oscillator is used in conjunction with the coincidence amplifier to obtain the delay. The blocking oscillator functions to generate the positive gating voltage. The positive gating pulse will have a time duration slightly longer than the time interval between two successive timing pulses. This will insure that at least one timing pulse will be coincident with the gating voltage. The one timing pulse that is coincident with the gating voltage will be amplified and inverted in the coincidence amplifier circuit.



233. —Generation of timing pulses.

The output of the first coincidence amplifier becomes a timing point from which accurate delays may be obtained. Its output may be used as a trigger for another blocking oscillator to generate another gating pulse. This gating voltage applied to another coincidence amplifier, to which the timing pulses are applied, will be coincident with the next timing pulse. The second coincidence amplifier will amplify and invert this timing pulse. The difference in timing between the output of the first and second coincidence amplifiers will be the exact interval of time between two successive timing pulses. Additional delays in multiples of this time interval may be obtained by the use of additional blocking oscillators and coincidence amplifiers.

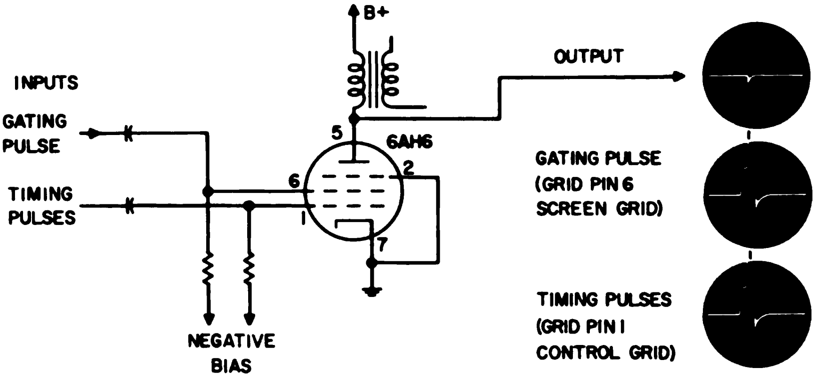

FROM 1ST BLOCKING OSCILLATOR (AT PRF)
TIMING WAVE
OUTPUT 1ST COINCIDENCE AMPLIFIER (AT PRF)
OUTPUT 2ND BLOCKING OSCILLATOR (AT PRF)
TIMING WAVE
OUTPUT 2ND COINCIDENCE AMPLIFIER (AT PRF)

234. —Coincidence amplifier timing diagram.

THE COINCIDENCE AMPLIFIER

How the Coincidence Amplifier Works

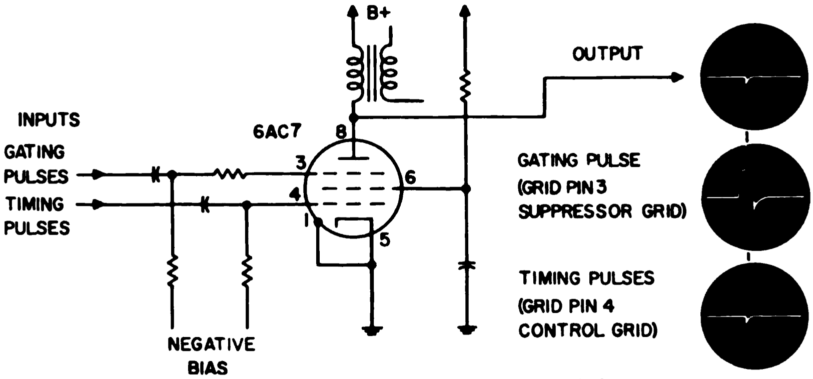
The coincidence amplifier circuit requires the simultaneous application of two input signals before an output signal can be produced. The tube is held in cut-off by negative bias voltages on both the control grid and the screen grid. To bring the tube into conduction requires that the two input signals be applied simultaneously to these two elements. One input signal will be applied to the control grid and the other will be applied to the screen grid of the coincidence amplifier tube. A positive signal on the control grid that raises the control grid voltage above cut-off will not permit plate current to flow unless the screen grid voltage is made positive at the same time. The positive gating voltage that is applied to the screen grid will raise the screen grid voltage to the desired level during the time of the gating pulse, but plate current will not flow unless the control grid voltage is raised above cut-off. This means that both input signals are required and the output signal will be produced during coincidence of these two signals.


B+
OUTPUT
INPUTS
GATING PULSE
TIMING PULSES
5
6AH6
6
2
1
7
NEGATIVE BIAS
GATING PULSE (GRID PIN 6 SCREEN GRID)
TIMING PULSES (GRID PIN 1 CONTROL GRID)

235.—Gating pulse applied to Coincidence amplifier screen grid.

Plate current will flow in the coincidence amplifier tube only during the time that both signals are applied. Since the gating voltage is of longer duration than the time between two timing pulses, at least one timing pulse will occur during the gate. This pulse will be amplified and the output from the plate will be a sharp negative pulse.

The circuit shown below is another variation of a coincidence amplifier. In this case, the suppressor receives the gating pulse and is biased negatively, as in the case of the screen grid in the one shown above. In all other respects, circuit operation is the same.

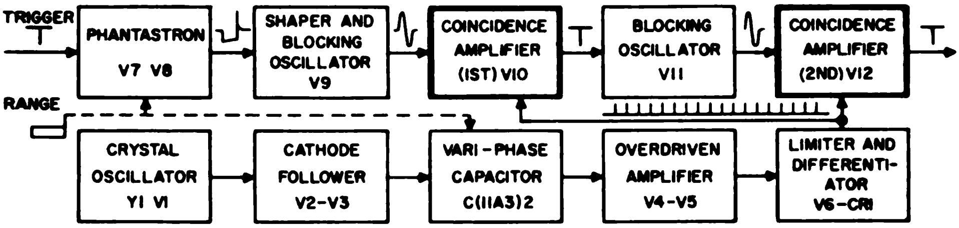

B+
OUTPUT
INPUTS
GATING PULSES
TIMING PULSES
6AC7
8
3
4
6
1
5
NEGATIVE BIAS
GATING PULSE (GRID PIN 3 SUPPRESSOR GRID)
TIMING PULSES (GRID PIN 4 CONTROL GRID)

236.—Gating pulse applied to coincidence amplifier suppresor grid.

THE COINCIDENCE AMPLIFIER

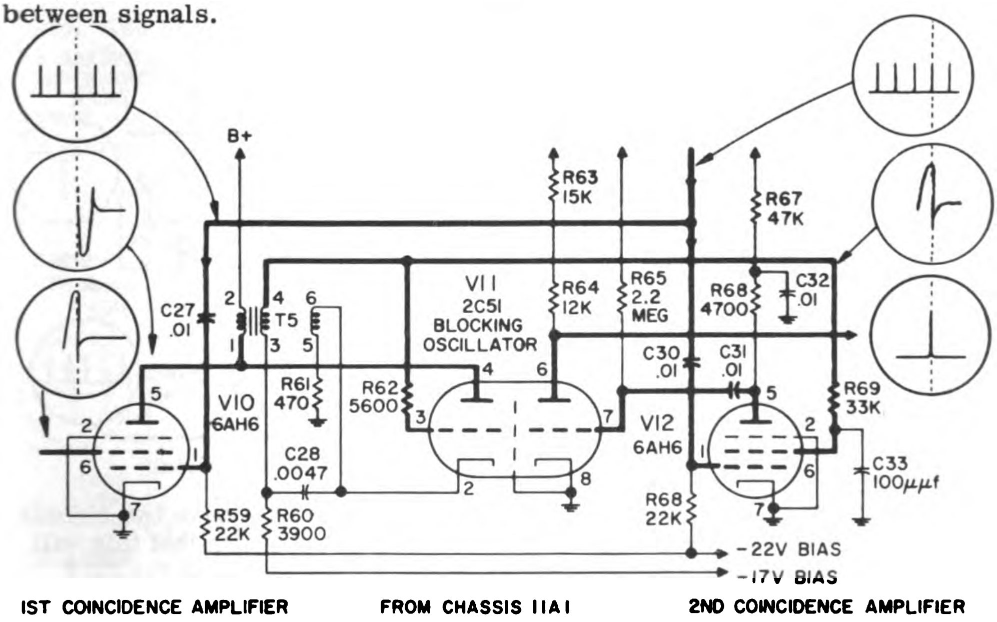
Applications

The application shown on this page is from Radar Equipment Mark 25 Mod 3. In modern fire control radars, you will find coincidence amplifiers used extensively in the Synchronizing and Range Determination Systems.


TRIGGER
PHANTASTRON V7 V8
SHAPER AND BLOCKING OSCILLATOR V9
COINCIDENCE AMPLIFIER (1ST) V10
BLOCKING OSCILLATOR V11
COINCIDENCE AMPLIFIER (2ND) V12
RANGE
CRYSTAL OSCILLATOR Y1 V1
CATHODE FOLLOWER V2-V3
VARI-PHASE CAPACITOR C(11A3)2
OVERDRIVEN AMPLIFIER V4-V5
LIMITER AND DIFFERENTIATOR V6-CR1

237.—Use of coincidence amplifier in Mark 25 Radar.

These circuits are used to produce the Range Pulse in the Mark 25 Radar. The output of the phantastron is shaped and applied to a blocking oscillator. Its output is an 8-microsecond gating pulse that is applied to the screen grid of V10. The rotation of the range shaft moves the variphase capacitor which controls the timing pips applied to the control grids of V10 and V12. V10 will conduct only when the gate and a timing pip are coincident. The resulting negative pulse from V10 triggers the next blocking oscillator which produces another 8-microsecond gate. This gate applied to V12 will gate the next timing pip. With the timing pips 6.1 microseconds apart, V12 will conduct 6.1 microseconds after V10. From this, you can see that these circuits are used to establish desired delays between signals.

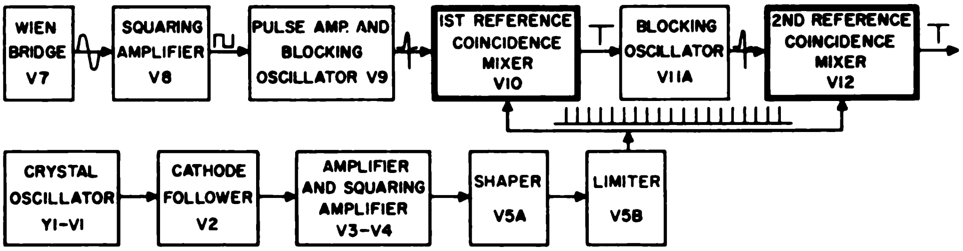


238.—Coincidence amplifier circuit in Mark 25 Radar.

Note that both control and screen grids are negatively biased. The only way that plate current can be made to flow in V10 and V12 is by the application of positive signals on the screen and control grids at the same time.

Applications (Continued)

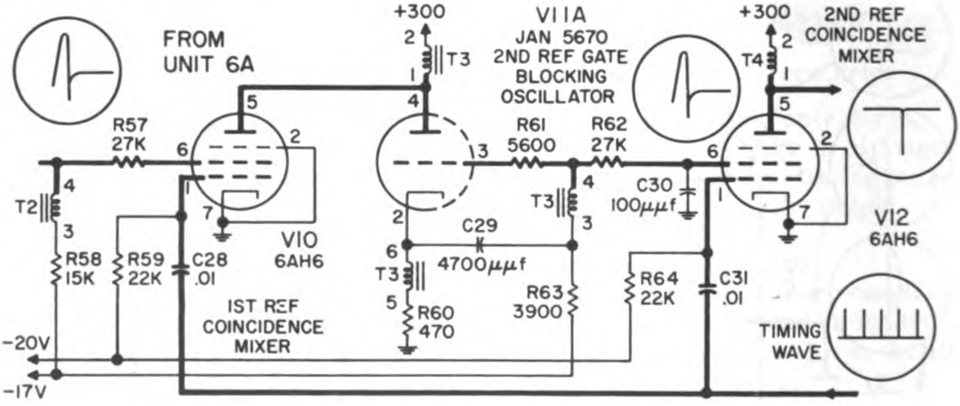
In this application from the AN/SPG-48, you will find the circuits and the block diagram are very similar to the one on the previous page. These circuits appear in the Synchronizing System of the radar instead of the Range Determination System. Most of the circuits in the block diagram have been discussed in your previous studies.


WIEN BRIDGE V7
SQUARING AMPLIFIER V8
PULSE AMP. AND BLOCKING OSCILLATOR V9
1ST REFERENCE COINCIDENCE MIXER V10
BLOCKING OSCILLATOR V11A
2ND REFERENCE COINCIDENCE MIXER V12
CRYSTAL OSCILLATOR Y1-V1
CATHODE FOLLOWER V2
AMPLIFIER AND SQUARING AMPLIFIER V3-V4
SHAPER V5A
LIMITER V5B

239.—Use of coincidence mixer in AN/SPG-48 Radar.

These circuits are used to establish the proper time relationships between the system timing pulses. The Wien bridge produces a low-frequency sine wave. This is used as the PRF and, after shaping, is applied as an 8-microsecond pulse to the first reference coincidence amplifier, V10.

Notice that in this radar they are referred to as coincidence mixers instead of amplifiers. The crystal oscillator produces the timing wave at a relative high frequency of 164 kc. Relative period time of the two frequencies is then about 500 microseconds for the PRF and 6.1 microseconds for the timing wave.



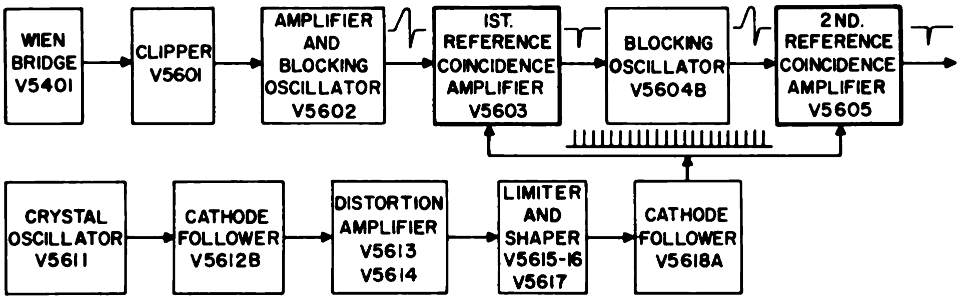
240.—Coincidence mixer circuit in AN/SPG-48 Radar.

As you know, the coincidence mixer (amplifier) must have two signals applied, which occur coincident in time. It can be seen then that this will only occur at the PRF rate. Thus, the output of V10 will be at the PRF.

The output of V10 triggers the blocking oscillator, V11A, which develops another 8-microsecond gating pulse. This is applied to the screen grid of V12, the second coincidence mixer, and gates the next timing pulse, which arrives 6.1-microseconds after V10 was triggered. The output pulse at the plate of V12 will occur 6.1 microseconds after V10 is triggered and its frequency will be that of the PRF.

Applications (Continued)

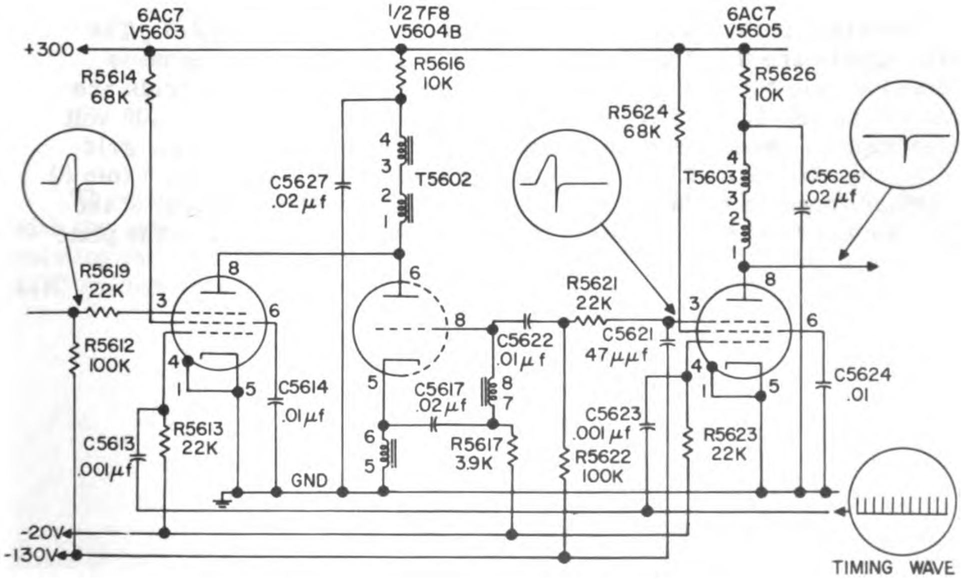
The application of coincidence amplifiers shown on this page is taken from the Mark 35 Radar, which is part of the Gun Fire Control System Mark 56.


WIEN BRIDGE V5401
CLIPPER V5601
AMPLIFIER AND BLOCKING OSCILLATOR V5602
IST. REFERENCE COINCIDENCE AMPLIFIER V5603
BLOCKING OSCILLATOR V5604B
2ND. REFERENCE COINCIDENCE AMPLIFIER V5605
CRYSTAL OSCILLATOR V5611
CATHODE FOLLOWER V5612B
DISTORTION AMPLIFIER V5613 V5614
LIMITER AND SHAPER V5615-16 V5617
CATHODE FOLLOWER V5618A

241. —Use of coincidence amplifier in Mark 35 Radar.

In this example, the coincidence amplifiers are found in the Synchronizing System and are used to perform the same function as in the example on the previous page. Note the close similarity between the block diagrams and also the schematics of the radars shown on this and the preceding page. It may interest you to know that they were not designed or manufactured by the same companies.

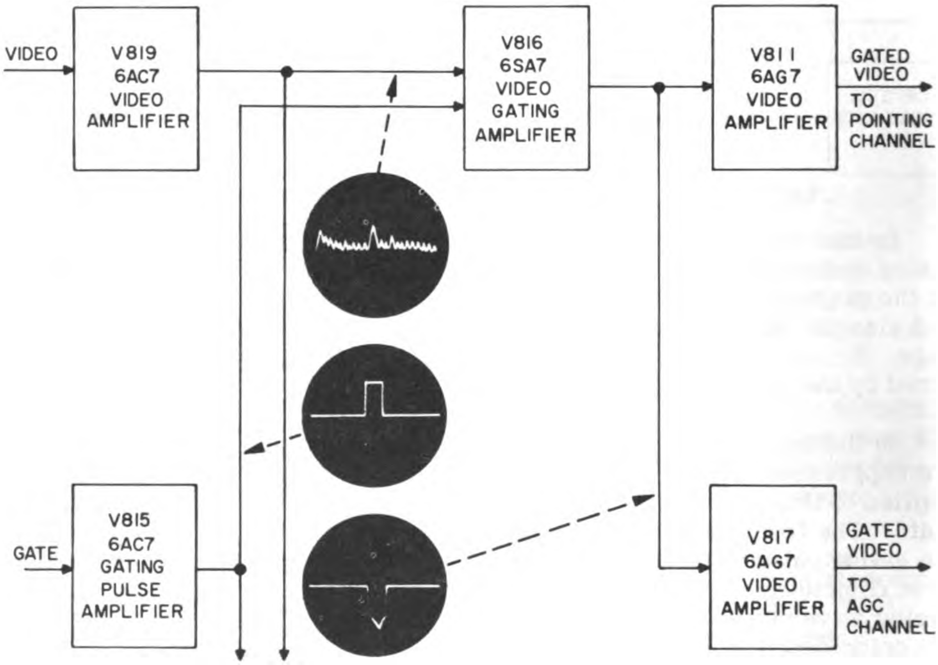
In the schematic, notice that in this case the gating pulse is applied to the suppressor grids which are biased at -130 volts. The timing wave is applied to the control grid as before. This grid is biased at about -20 volts. The frequency of the timing wave is 164 kc, while the frequency of the gating pulse is the same as the PRF. The gating pulse arrives at the first coincidence amplifier as a pulse of 8-microsecond duration. The timing wave pulses last for about 1 microsecond. Therefore, the output of the coincidence amplifiers is a pulse of 1-microsecond duration.



242. —Coincidence amplifier circuit in Mark 35 Radar.

Applications (Continued)

The next circuit is from the Mark 34 Radar. It is not referred to as a coincidence amplifier, but is called a video gating amplifier. It may be considered as a coincidence amplifier. Two signals are required as the inputs to the tube and the desired output is obtained when the two input signals are coincident. The two input signals are video signals and a range gating signal. The output is a gated video signal.

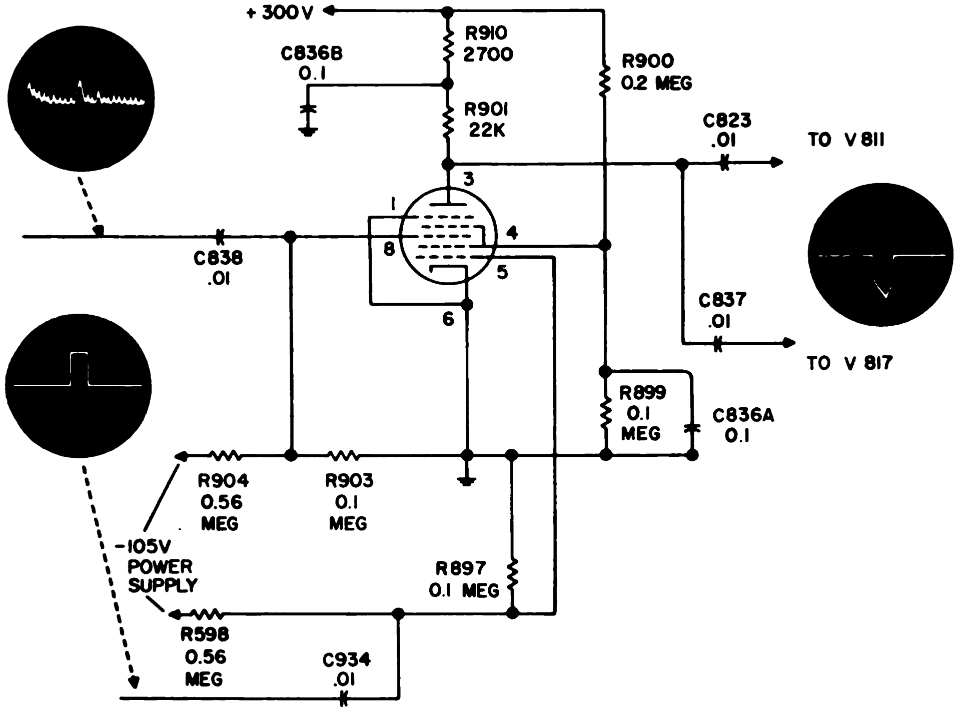


243.—Use of video gating amplifier in Mark 34 Radar.

The video gating amplifier is a pentagrid tube (6SA7), V816. The video signals are injected at grid No. 3 (pin 8). The gating signal is injected at grid No. 1 (pin 5), the control grid. Both of these grids are biased to about -16 volts from the voltage dividers across the -105 volt power supply. When the gating pulse is not applied to the control grid (pin 5), the -16 volts of bias will hold the tube cut off. Grid No. 3 (pin 8) is farther from the cathode and has less control of plate current of the tube. As a result, low-amplitude gate signals are developed in the plate

Applications (Continued)

circuit, even without positive video signals being applied to grid No. 3. These gate signals will have constant amplitude. However, video signals occurring at a time that there is not a gating pulse on the control grid will not enable the tube to pass plate current. Only video that is coincident with the gate signal will be amplified in V816 and coupled to the next two video amplifiers, V811 and V817. The outputs of V811 and V817 will be used in the pointing channel and the AGC (automatic gain control) channel of the radar.



244.—Video gating amplifier in Mark 34 Radar.

The video gating amplifier selects only the video that is coincident with the range gating signal and this gated video is used as the source of pointing information. Also, V816 makes possible the development of an AGC voltage that is dependent upon the amplitude of the gated video.

THE COINCIDENCE AMPLIFIER

Review

In this topic, you have studied the coincidence amplifier. This circuit is found in the synchronizing and ranging circuits of fire control radar equipments.

The principal points that you will want to remember about the coincidence amplifier are:

1. A coincidence amplifier requires the presence of two signals applied to the tube at the same instant in order that plate current will flow.
2. In the absence of signals on the selected grids of the tube, these grids will be biased below cut-off by a negative voltage obtained from a power supply.
3. One of the two signals to a coincidence amplifier will be applied to the control grid of the tube.
4. The second of the two signals may be applied to either the screen grid or the suppressor grid.
5. The signal applied to the control grid is usually a pulse of very short duration and reoccurring at a fast repetition rate.
6. The signal applied to the screen grid, or suppressor grid, is of longer duration and occurs at a slower repetition rate, usually at the PRF of the radar.
7. The signal on the screen grid, or suppressor grid, is usually the gating signal.
8. The signal applied to the control grid is amplified in the tube if the gating signal occurs in coincidence with the control grid signal.
9. Coincidence amplifiers are used with blocking oscillators to obtain accurate delays. These delays will be in multiples of the time interval between successive timing pulses that are applied to the control grids of the coincidence amplifiers.
10. In the technical reference material for some fire control radar equipments, you will find the coincidence amplifier referred to as a coincidence mixer.

Notes

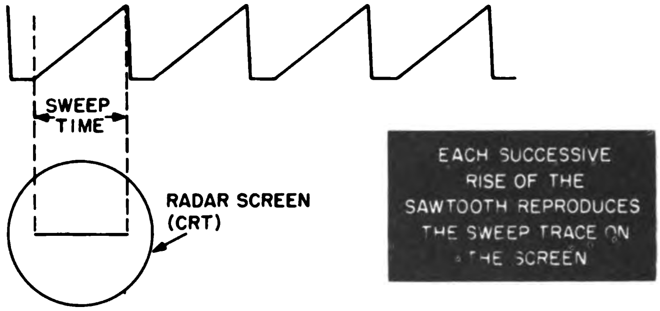
TOPIC 12: SAWTOOTH GENERATORS

General Purpose

The next circuit that you are going to study, and one that you will work with in your chassis, is the sawtooth generator.

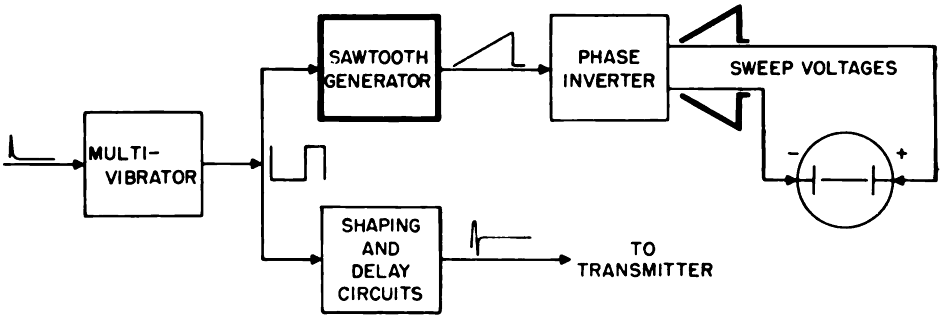
Sawtooth generator circuits are employed in the range sweep circuits of fire control radar equipments. They will also be encountered in the ranging systems of some fire control radars. You have been observing the effects of sawtooth generators every time that you have used your oscilloscope; they are used to produce the time base (horizontal sweep) on the screen of the cathode-ray tube.

As their name implies, the output waveform of a sawtooth generator resembles the teeth of a carpenter's saw.


SWEEP TIME
RADAR SCREEN (CRT)
EACH SUCCESSIVE RISE OF THE SAWTOOTH REPRODUCES THE SWEEP TRACE ON THE SCREEN

245. —Sawtooth generator output waveform.

It is desirable that the sweep voltage applied to a cathode-ray tube be as nearly linear as possible. This means that the sweep should move across the screen at the same rate during the entire sweep time. For example, if in the first 20 microseconds the sweep moves 1 inch on the screen, then for each successive 20-microsecond period it should move another inch. The sawtooth generator used in the ranging system of fire control radars must produce an output which is linear over the entire range limits of the system in which it is used. This is necessary because they are used to determine range, which is a linear quantity.



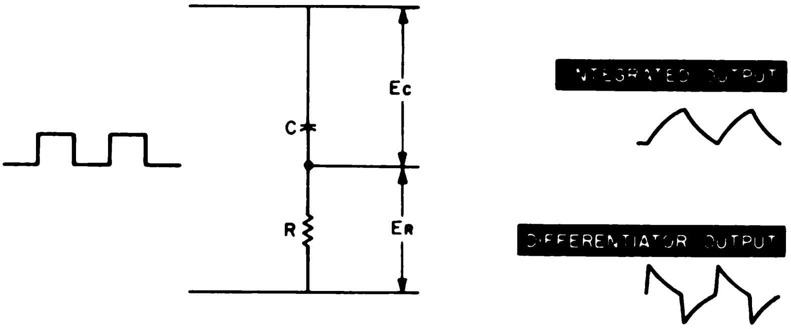
246. —Generation of cathode-ray tube sweep voltages.

SAWTOOTH GENERATORS

General Information

The sawtooth generator circuit is made up of the following components: a resistor, a capacitor, and either a gas tube or a vacuum tube. Most of the sawtooth generators used in fire control radars use a vacuum tube; this is the type you will work with in your chassis.

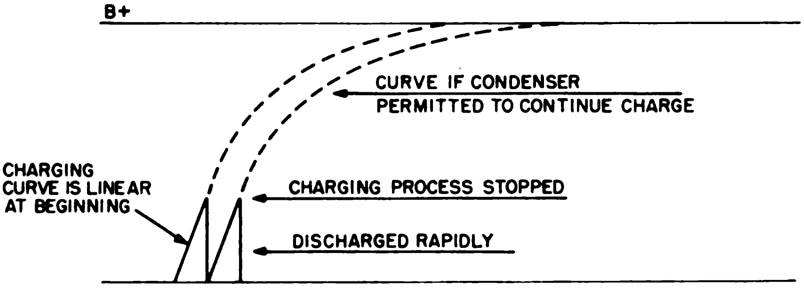
In your study of sawtooth generators, you will find that their operation is based on the principles you learned in topic 5, "Differentiating Circuits." However, the output of a sawtooth generator is the integrated output of an R-C circuit; it is taken from across the capacitor.



247. —Typical sawtooth generator R-C circuit.

As you have previously learned, an R-C circuit contains a d-c voltage source, a series resistor, and a condenser. When these components are connected, the condenser will start to charge. Since the resistor limits the current, the charge will not be instantaneous, but at a rate which is exponential. The charging curve is quite linear in the very beginning, as shown in the diagram below, and, in the sawtooth generator, the condenser charging process is usually stopped before the slope of the charging curve changes appreciably. After the charging stops, the condenser discharges, and the events just described repeat and the condenser recharges.

Most time-base generators use this very same charging and discharging process. Any circuit differences that exist result largely from the methods employed for high-speed switching of the condenser from charge to discharge.

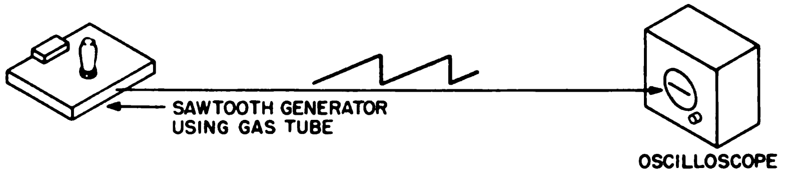


B+
CURVE IF CONDENSER PERMITTED TO CONTINUE CHARGE
CHARGING CURVE IS LINEAR AT BEGINNING
CHARGING PROCESS STOPPED
DISCHARGED RAPIDLY

248. —Sawtooth generator charging curves.

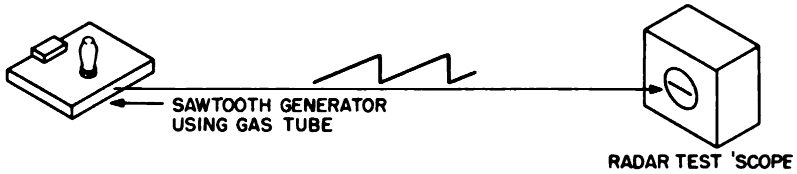
Types of Sawtooth Generators

There are two general types of sawtooth generators that are used in radar systems. These are the sawtooth generator using the gas tube and the sawtooth generator using a vacuum tube.



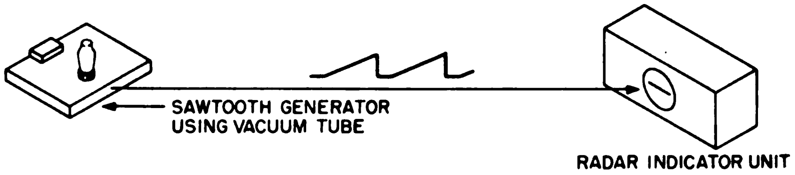
249.—Gas tube sawtooth generator for oscilloscope.

A sawtooth generator using a gas tube provides sweep voltage for the cathode-ray tube in laboratory-type 'scopes. This generator may be free-running or it may be synchronized internally or externally.



250.—Gas tube sawtooth generator for radar test oscilloscope.

When a radar indicator is used as a test 'scope, the sweep voltage for the cathode-ray tube is obtained in the same manner as for radar indicator presentations.



251.—Vacuum tube sawtooth generator for radar indicator unit.

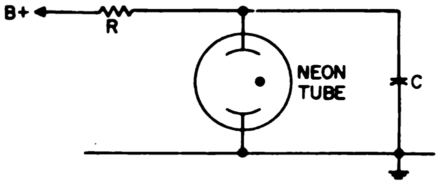
A sawtooth generator using a vacuum tube provides the sweep voltage for the range 'scope in a radar range indicator unit. This type of sawtooth generator is controlled by the output of a multivibrator which establishes the frequency and the width of the sweep voltage.

The addition of the tube, gas or vacuum, to the R-C circuit provides a short discharge time for the capacitor. The capacitor will charge through the resistance and will discharge through the tube. The charge time is long, and is determined by the values of resistance and capacitance. However, it is desired that the sweep voltage be as linear as is possible and, in order to meet this requirement, only the beginning portion of the capacitor charge curve is used. After a fraction of an R-C time constant has elapsed, during which the capacitor is charging, the capacitor will be discharged through the tube. The discharge of the capacitor through the tube produces the negative-going portion of the sawtooth waveform.

SAWTOOTH GENERATORS

Neon-Tube Sawtooth Generator

The neon-tube sawtooth generator is the simplest form of the sawtooth generator circuit. It consists of a resistor, a capacitor, a neon tube, and a source of B+ voltage.

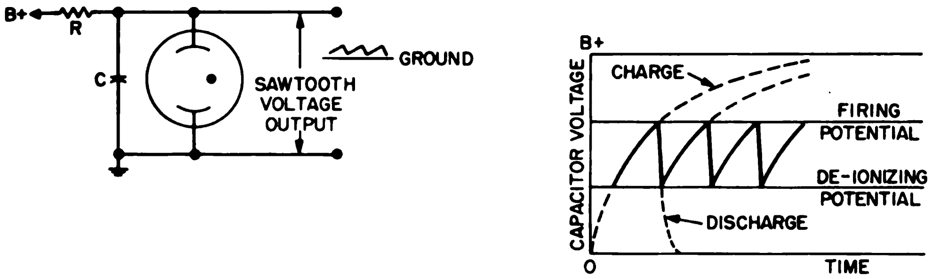


252. —Neon sawtooth generator elements.

You know that if a resistor and capacitor are connected in series across a voltage source, the capacitor will gradually charge until the voltage across it approaches the source voltage. You know that the larger the resistor or the capacitor, the longer will be the time required for the capacitor to charge to the applied voltage; the time can be calculated from the R-C time constant. The buildup of voltage with time follows the familiar capacitor charging curve.

A neon tube ionizes and conducts when the voltage across its electrodes reaches the firing potential. Conduction of current through the neon tube results in a large voltage drop across the series resistor and reduces the voltage across the electrodes of the neon tube. The tube will extinguish itself as soon as the voltage across its electrodes drops below the de-ionizing potential. Thus, the neon tube acts as a very low resistance when it is ionized and acts like an open switch when it is de-ionized.

The sawtooth generator components are connected together as shown below. The capacitor charges, following the R-C charging curve, until the firing potential of the neon tube is reached. The neon tube ionizes and acts as a very low resistance across the capacitor. The capacitor discharges very rapidly through the tube, following a very rapid discharge curve. As soon as the voltage across the capacitor drops below the de-ionizing potential of the neon tube, the tube extinguishes itself and no longer conducts. The capacitor starts to recharge and the cycle begins over again. The resulting voltage across the capacitor is a sawtooth wave with a slightly rounded charging curve.



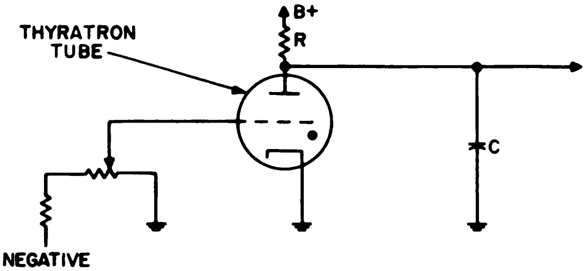
253. —Neon sawtooth generator capacitor voltage curves.

The Thyratron Sawtooth Generator

The purpose of the thyratron is to provide a high-speed switching action, so that the capacitor can be readily discharged. When the thyratron is cut off, the capacitor will charge at a rate determined by the R and C values in the circuit.

A thyratron is a gas tube that operates on the same principles as the neon gas tube. The characteristics are similar in each case. In the thyratron, some value of plate voltage is required before the gas will ionize and the tube conduct. This value of plate voltage is called the ionization voltage.

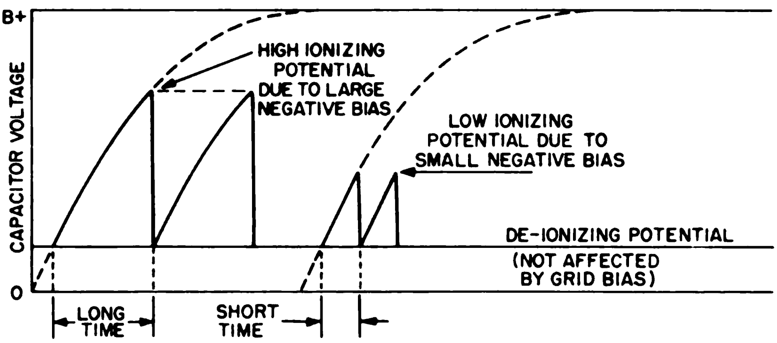
Once the tube becomes ionized, it will continue to conduct until the plate voltage drops to some value lower than the ionizing potential. This low value of plate voltage is called the de-ionizing potential and the tube ceases to pass current at this time.



254.—Thyratron sawtooth generator.

The thyratron is constructed with one or more additional tube elements which are called control grids. In a thyratron, the control grids will keep the tube cut off until the plate potential reaches a value at which the grid potential is no longer sufficient to prevent current flow. When the plate voltage rises to this value, the gas becomes ionized and the tube conducts.

In a thyratron that is conducting, increasing the negative grid potential will not affect tube current. The thyratron stops conducting only when the plate voltage drops to the de-ionizing potential. At that time, the grid will again take control, and keep the tube cut off, until plate voltage again rises to a value at which the grid loses control and the tube becomes ionized. As the atoms of gas lose electrons, they acquire a net positive charge. When this occurs, the atoms become ions. These ions are free to move as a gas. As the grid becomes more negative, the ions are attracted to it. This results in a neutralization of the charge on the grid, preventing it from having control of the tube current during conduction.

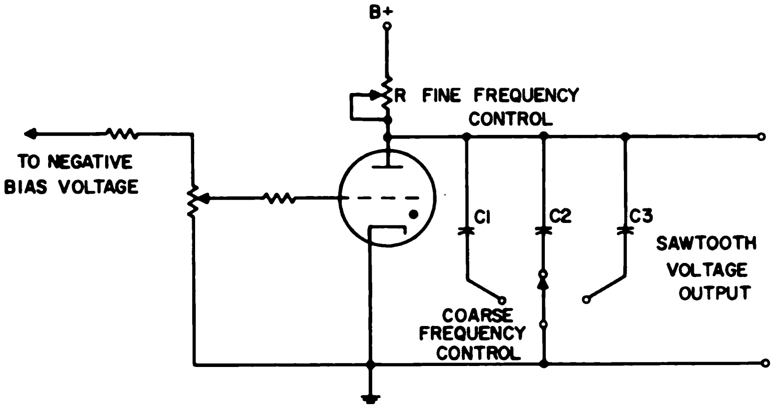


255.—Thyratron sawtooth generator plate voltage curves.

The Thyratron Sawtooth Generator (Continued)

The thyratron sawtooth generator is the type used in many general-purpose test oscilloscopes. The sweep voltage output will be determined by the ionizing, or firing, potential of the tube and the time constant in the capacitor charging path. Since the circuit will operate to develop a sweep voltage at a rate determined by factors within the circuit itself, it is said to be "free-running." To make this sweep voltage effective for use in viewing waveforms, some means must be provided for controlling the rate at which the sweep voltage is generated. This is necessary in order that the waveform being observed will appear to be stationary on the face of the cathode-ray tube.

Two methods are used for changing the free-running frequency of the thyratron-type sawtooth generator. One method is to change the firing potential of the tube and the other is to change the R-C time constant in the capacitor charging path.



256.—Frequency variation due to change in R-C time constant.

Changing the firing potential of the tube will change the free-running frequency of the sawtooth generator. A change in the grid bias applied to the thyratron will change the firing potential. It can be seen from the diagram on the opposite page that a decrease in grid bias will lower the firing potential of the tube and will increase the repetition rate of the developed sweep voltage. Likewise, an increase in the grid bias will increase the firing potential of the tube and decrease the repetition rate of the developed sweep voltage.

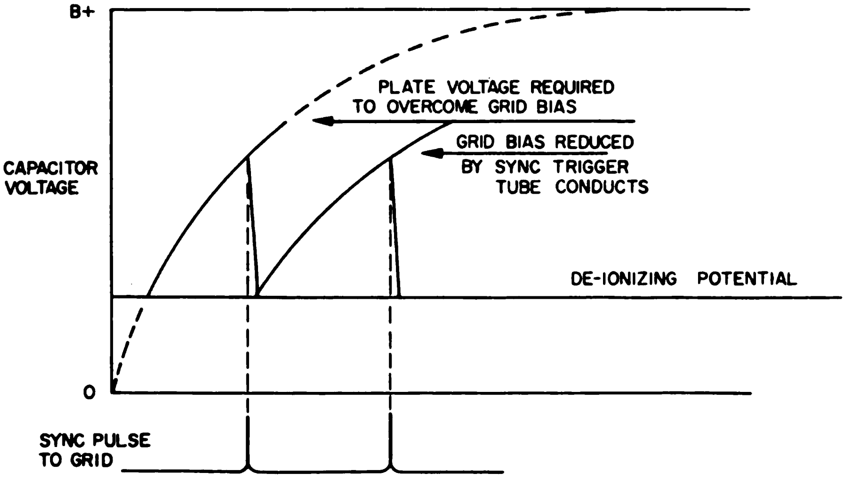
Changing the R-C time constant in the capacitor charge path will change the free-running frequency of the thyratron sawtooth generator. A change in the R-C time constant may be accomplished in two ways—either a change in the capacitance or a change in the resistance. Both ways are used in controlling the frequency. Using a switch to change capacitors in the R-C circuit will provide a large change in the frequency. This switch provides the COARSE change in frequency. Small changes in the R-C time constant may be obtained by making the resistor variable. The variable resistor provides the FINE control of frequency.

The Thyratron Sawtooth Generator (Continued)

The sawtooth generator circuits employed in the oscilloscopes that you have been using are designed so that a synchronizing voltage can be applied to the control grid of the tube.

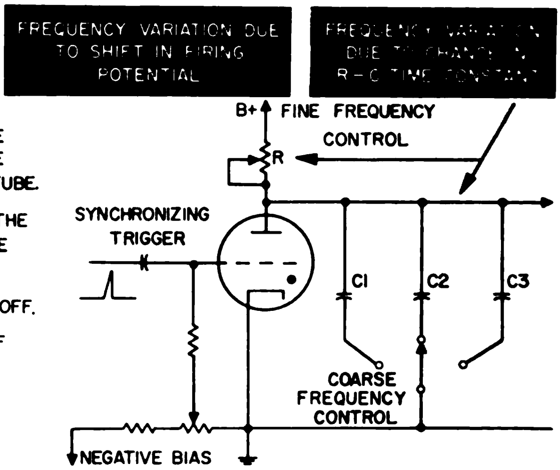
In sawtooth generators that use thyratron tubes, this voltage is applied to the grid to cause the tube to conduct. When the tube ionizes, it rapidly discharges the capacitor. When the plate drops to the de-ionizing potential, the tube stops conducting and the fixed bias voltage on the grid keeps it cut off. When the tube is cut off, the capacitor starts to charge toward B+.

If the capacitor is allowed to charge for a long enough time, it will reach a potential which will be great enough to overcome the grid bias. To keep the output of the sawtooth generator synchronized with the synchronizing pulses, it is necessary that they occur at a higher frequency than the free-running frequency of the sawtooth generator.



KEYS TO THYRATRON OPERATON

1. FOR A GIVEN BIAS ON THE GRID, THERE IS A CERTAIN VALUE OF PLATE VOLTAGE REQUIRED TO IONIZE THE GAS IN THE TUBE.
2. THE TUBE STOPS CONDUCTING WHEN THE PLATE REACHES SOME LOW VALUE, THE DE-IONIZING POTENTIAL.
3. THE GRID BIAS KEEPS THE TUBE CUT OFF.
4. THE GRID CANNOT SHUT THE TUBE OFF WHILE IT IS CONDUCTING.

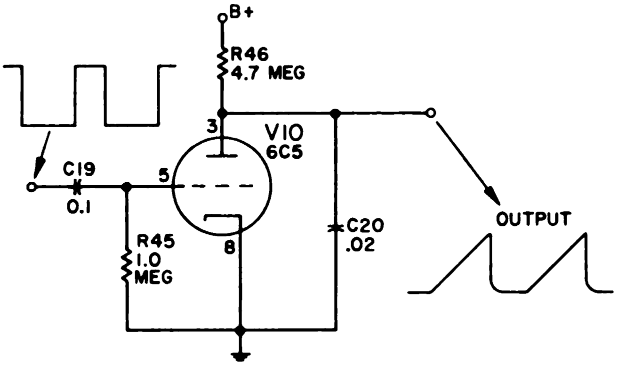

FREQUENCY VARIATION DUE TO SHIFT IN FIRING POTENTIAL
FREQUENCY VARIATION DUE TO CHANGE IN R-C TIME CONSTANT
B+
FINE FREQUENCY CONTROL
R
SYNCHRONIZING TRIGGER
C1
C2
C3
COARSE FREQUENCY CONTROL
NEGATIVE BIAS

257.—Thyratron sawtooth generator operation.

Vacuum-Tube Sawtooth Generator

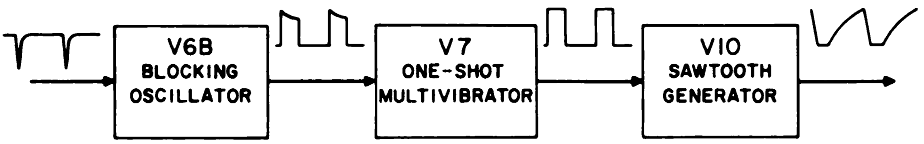
More accurate sweep voltages are required to produce the range sweep for a radar indicator. The repetition frequency of the range sweep must be the same as the pulse repetition frequency (PRF) of the radar. The starting time, stopping time, and the duration of the sweep are all critical. To meet these requirements, a vacuum-tube sawtooth generator circuit is used.

In the vacuum-tube sawtooth generator circuit, cut-off and conduction of the tube controls the charge and discharge of the capacitor. The tube is normally conducting and the charge across the capacitor is the voltage across the tube. This circuit is controlled by the square-wave output of a multivibrator. The negative portion of the square wave will cut off current flow in the tube and the capacitor will charge toward B+ through the resistance. The tube will conduct during the positive portion of the square wave and the capacitor will discharge through the tube. The repetition rate of the square wave will be the same as the PRF of the radar. The duration of the negative portion of the square wave will be the duration of the sweep. The time of occurrence of the leading edge of the negative-going portion of the square wave must be synchronized with other circuits of the radar.



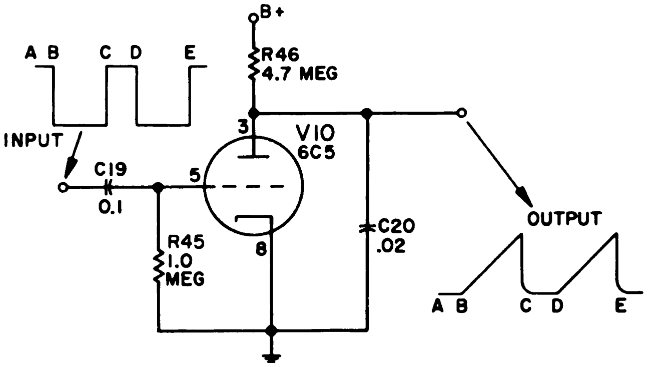
258.—Vacuum-tube sawtooth generator.

The schematic on this page is of the sawtooth generator in the fire control radar special circuits chassis. It is the circuit that you will work with for observation of waveforms and trouble shooting. The square wave used to control the operation of the sawtooth generator is obtained from plate pin 5 of the one-shot multivibrator, V7.



259.—Use of vacuum-tube sawtooth generator in special circuits chassis.

Vacuum-Tube Sawtooth Generator (Continued)



260. —How the vacuum-tube sawtooth generator works.

When a square wave is fed into the sawtooth generator circuit at time A, the input to the generator is positive and the tube is conducting. The voltage across the .02-mfd capacitor is equal to the small drop across the tube.

At time B, the square-wave input falls in value and causes a negative voltage to be developed across the 1.0-meg grid resistor, which cuts the tube off. As the tube cuts off, the .02-mfd capacitor starts to charge toward B+. The charging path is through the 4.7-meg plate resistor.

The tube is held at cut-off for the duration of the negative square-wave peak, time B to C. During this time, the voltage across the .02-mfd capacitor is rising as the capacitor charges.

At time C, the input voltage rises sharply, causing the tube to conduct immediately. When the tube conducts, it causes the capacitor to stop charging and to discharge quickly through the relatively low resistance of the tube circuit.

From time C to D, the tube continues to conduct and the voltage across the capacitor remains constant at the value of E_p, the drop across the tube.

At time D, another negative square-wave peak is fed into the generator, which causes another sawtooth to be formed in the output.

Experiment—Sawtooth Generator; Test Setup

You have seen on the preceding pages that the output of a sawtooth generator is the exponential rise of voltage as the capacitor charges toward B+. If it is desired that the sawtooth output be linear, it is necessary that the R-C time constant be long compared to the frequency of the trigger pulses. In this way, only a small portion of one R-C time constant of the circuit will be used. Since the beginning of the charging curve of the capacitor is linear, only this portion is used.

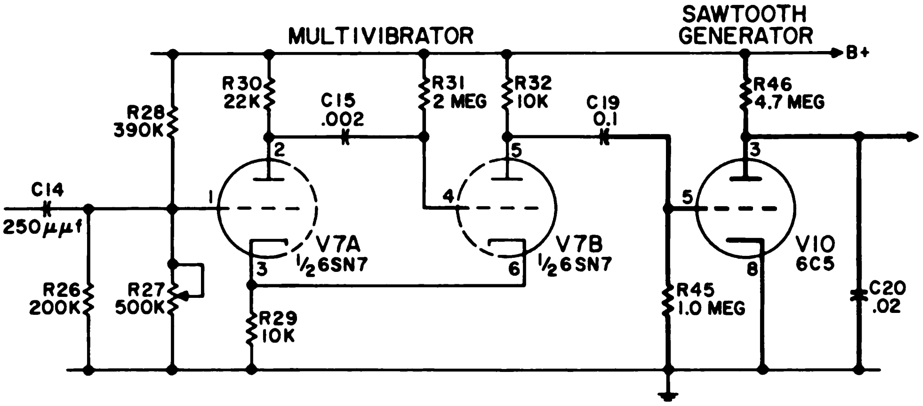
However, there are other factors to be considered. If the R-C time is made too long compared to the trigger frequency, the capacitor will only charge a very small amount and the output voltage may be insufficient to drive the following tube circuits.

In the following experiments, you will see the effect on the output waveform when the R-C time is decreased. You will then conduct an experiment with a circuit that has a very long R-C time constant.

You are now going to experiment with the sawtooth generator circuit in your chassis.

For this experiment, you will require the following items:

1. Oscilloscope
2. 6C5 vacuum tube (V10)
3. 0.1-megohm resistor
4. 1.0-mfd capacitor

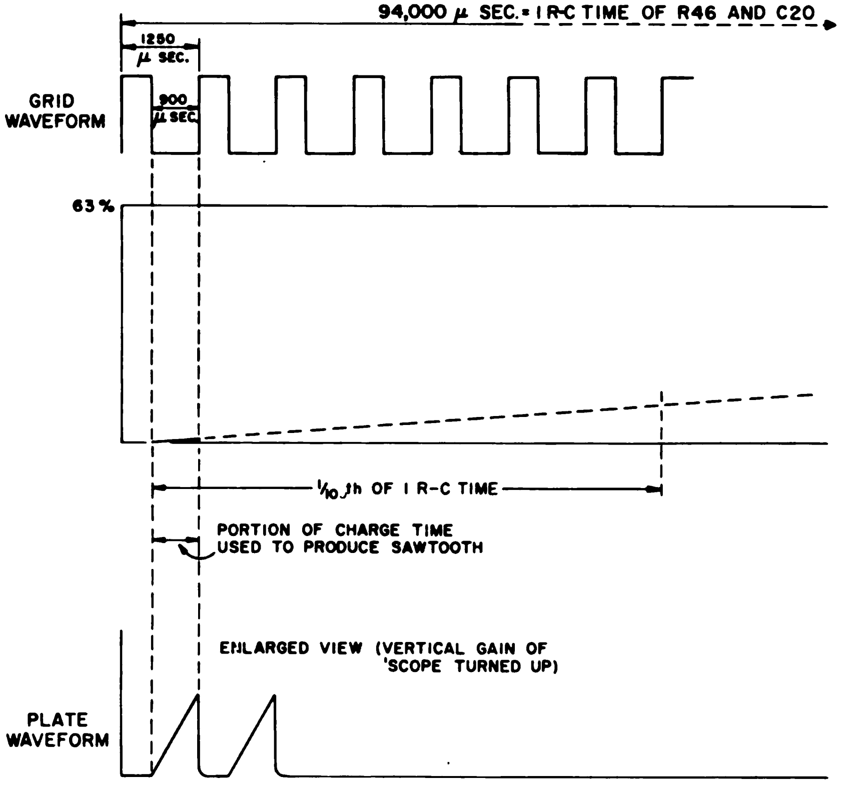


261.—Sawtooth generator—test setup.

Experiment—Sawtooth Generator; Checking Waveforms

In this experiment, you will check the waveforms in the sawtooth generator circuit in your chassis.

1. Observe the square-wave input to the sawtooth generator at grid pin 5 of V10.
2. Observe and note the point at which the leading edge of the negative portion of the square wave appears on the face of the 'scope.
3. Place 'scope probe at plate pin 3 of V10 and observe the waveform. Notice that the point at which the waveform starts to rise coincides with the leading edge of the negative portion of the square wave.


94,000 μ SEC. = 1 R-C TIME OF R46 AND C20
1250 μ SEC.
GRID WAVEFORM
900 μ SEC.
63%
1/10th OF 1 R-C TIME
PORTION OF CHARGE TIME USED TO PRODUCE SAWTOOTH
ENLARGED VIEW (VERTICAL GAIN OF 'SCOPE TURNED UP)
PLATE WAVEFORM

262.—Sawtooth generator—checking waveforms.

Experiment—Sawtooth Generator; Linearity

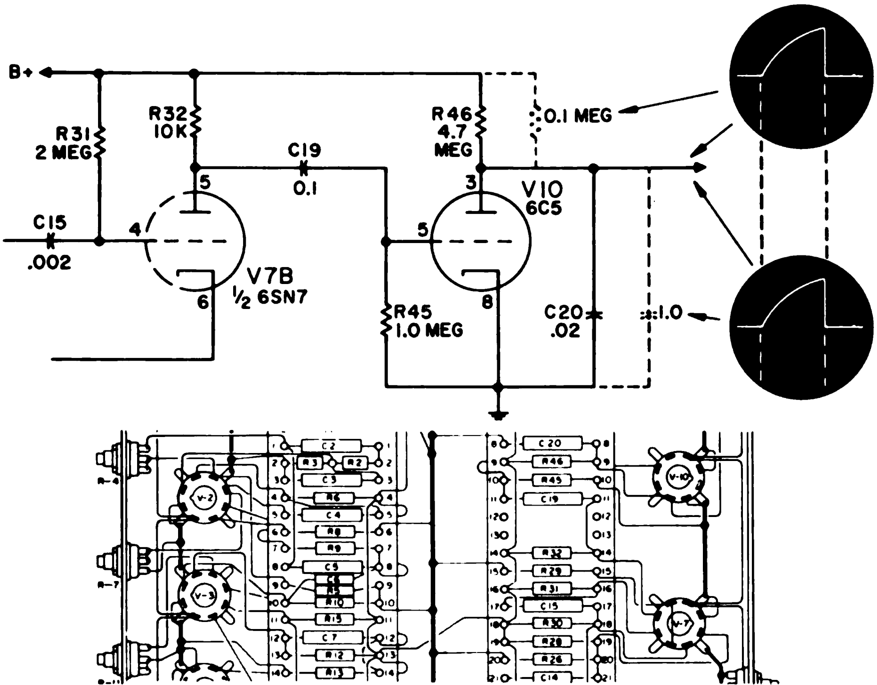
You are now going to observe the effects of variations in the R-C time constant on the output of the sawtooth generator.

1. Secure power to the chassis.

2. Connect a 0.1-megohm resistor in parallel with R46 (B-9L to B-9R).

3. What is the new time constant of the circuit?

4. Place 'scope probe on plate pin 3 of V10 and energize the equipment. Note the waveform. Is the waveform as linear as it was before you inserted the resistor? What is the comparative amplitude of the two waveforms?



263. —Sawtooth generator—checking linearity.

5. De-energize the equipment and connect a 1.0-mfd capacitor in parallel with C20 (B-8L to B-8R).

6. Energize the chassis and observe the waveform at plate pin 3 of V10.

Has the linearity been improved? Why?

What is the R-C time of the circuit with the added capacitance?

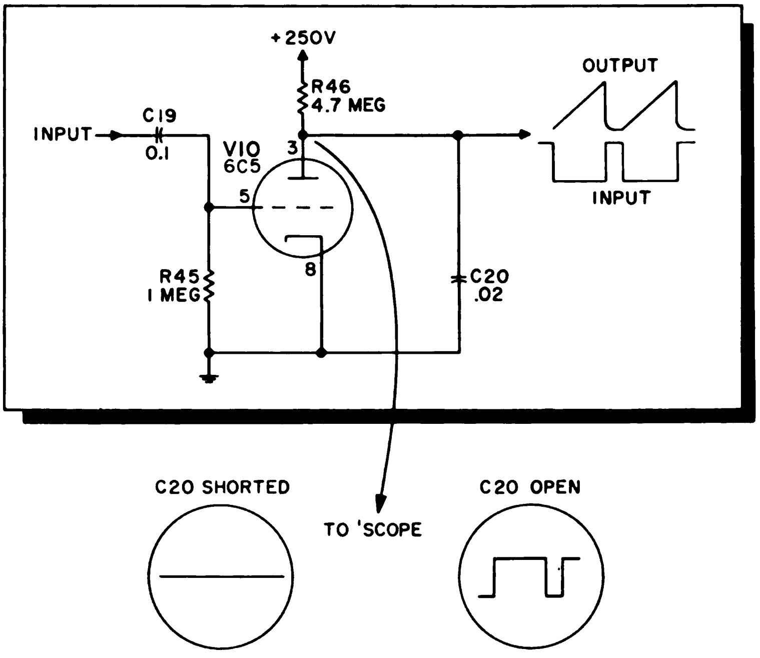
What would happen to the waveform linearity if the 0.1-megohm resistor were removed from the circuit?

7. Restore the chassis to normal.

Experiment—Trouble Shooting

In signal tracing the sawtooth generator, there are only two points at which the circuit can be checked—the square wave at the grid and the sawtooth at the plate.

If the input is correct and the output is either distorted or missing entirely, the trouble lies with the sawtooth generator. If, for example, there is no output and the tube is known to be good, the charging capacitor may be shorted. A zero voltage reading on the plate will indicate such a trouble. If, however, the capacitor is open, a square wave will appear in the plate because, when the tube is cut off, the plate voltage will immediately rise to the B+ level.



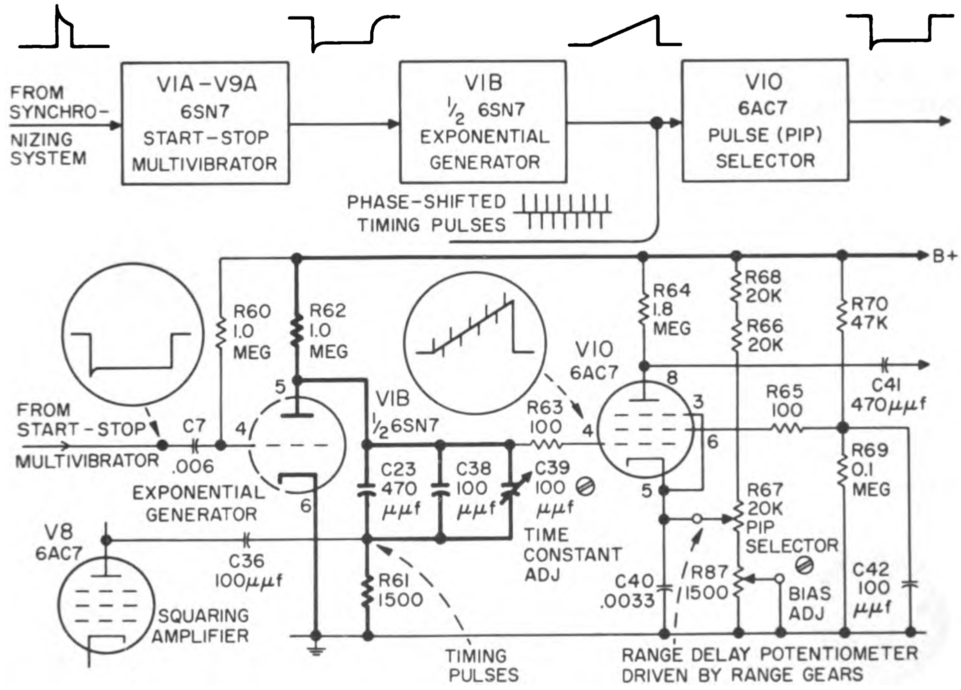
264.—Sawtooth generator—trouble shooting.

As you have done in the past, you and your partner will now insert troubles into each other's chassis and will service them, using a logical procedure. You may insert troubles in the sawtooth generator circuit or in any of the driving circuits.

Applications

Examples of the sawtooth generator are found in sweep generating circuits and ranging circuits in fire control radar equipments. Sawtooth generators used to develop sweep waveforms for radar indicators must meet a number of requirements that make these circuits more complex than the basic circuit. These requirements are good linearity, specific sweep duration, and a certain sweep starting time.

The first example of the sawtooth generator is from Radar Equipment Mark 34. This sawtooth generator is used to develop an exponential voltage rise that is nearly linear. This exponential voltage rise, with timing pulses superimposed upon it, is used to control the time of starting conduction in a vacuum tube. One of these timing pulses, plus the exponential rise in grid voltage, will bring the pulse selector tube out of cut-off.



265. —Sawtooth generator in Mark 34 Radar.

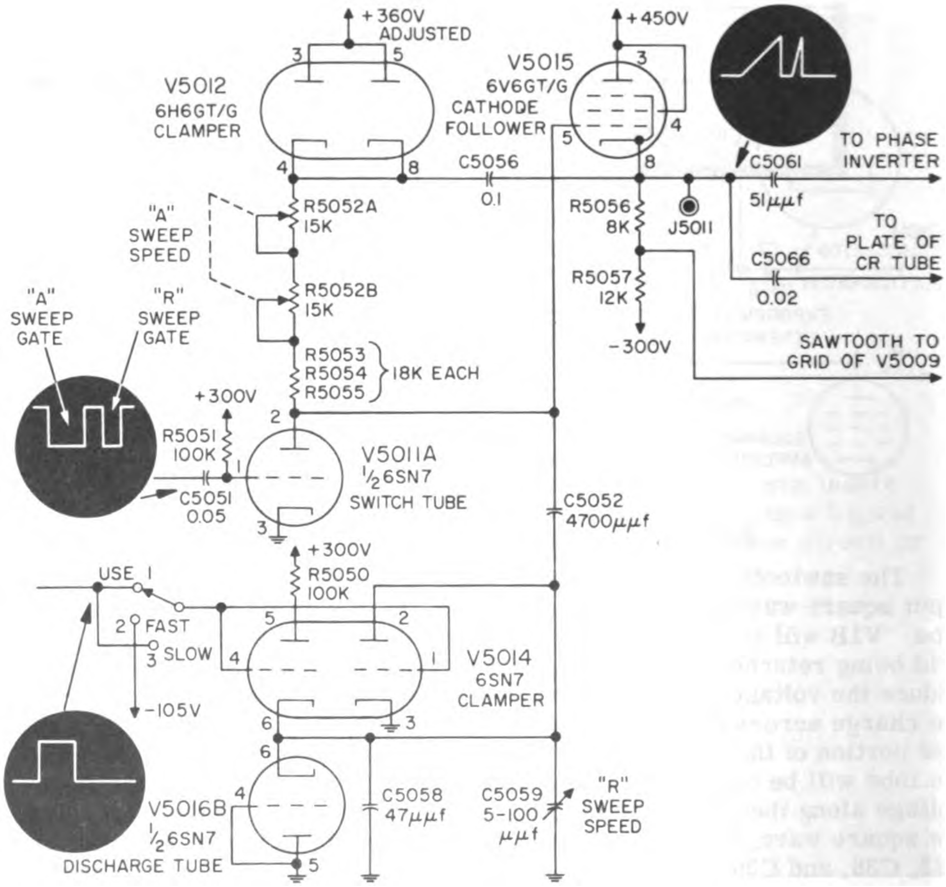
The sawtooth generator tube is V1B. When the positive portion of the input square wave is applied to grid pin 4, plate current will flow in the tube. V1B will conduct heavily because of this positive voltage and the grid being returned to B+ through R60. Plate current through the tube will reduce the voltage at plate pin 5 to some low value. This voltage will be the charge across parallel capacitors C23, C38, and C39. When the negative portion of the square wave is applied to grid pin 4, plate current in the tube will be cut off and these capacitors will charge toward the B+ voltage along the exponential curve. At the end of the negative portion of the square wave, V1B will conduct again, and will discharge capacitors C23, C38, and C39. Notice that C39 is a variable capacitor and is labeled TIME CONSTANT ADJ. This capacitor is adjusted for improved linearity in the exponential waveform.

Applications (Continued)

The next example of the use of this special circuit is the sweep generator circuit in Radar Equipment Mark 35. The sweep generator section consists of the sawtooth generator, a sweep-switch tube, a discharge tube, a feedback circuit, associated clamping tubes, and a cathode follower.

This sweep generator alternately develops an "A" and an "R" sweep waveform. Each sweep will be produced at a repetition rate of one-half of the PRF of the radar. Since the "R" sweep is very short compared to the "A" sweep, a gated clamping tube is used to change the R-C time constant in the sawtooth generator circuit. A feedback circuit is provided to develop a linear sweep, instead of the exponential voltage rise that would be developed by the basic sawtooth generator circuit. Controls are provided for adjusting the amplitude of each of the sweep waveforms.

At first glance, this circuit appears to be rather complex. Let us find the basic sawtooth generator circuit. By breaking the circuit into its separate functions, its operation will be much easier to understand. This is the approach that you probably will use as you encounter some of the more complex circuits in the radar equipments.

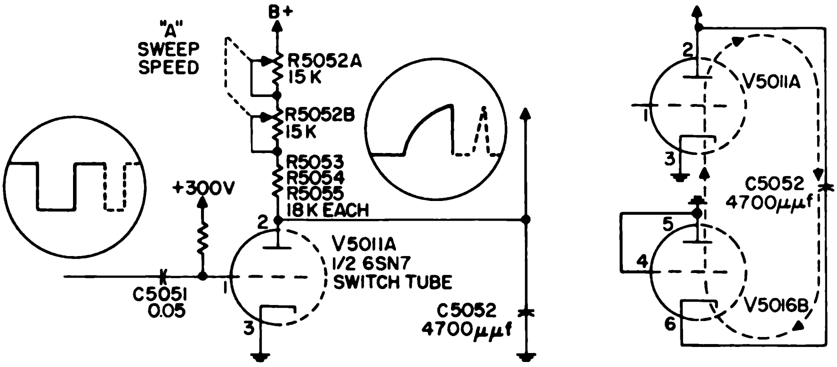


266. —Sweep generator circuit in Mark 35 Radar.

Applications (Continued)

Look first at the clamp tube, V5014. This tube is a 6SN7 with its two sections wired in series. When the positive gate signal is applied to grid pins 1 and 4, both sections of the tube will conduct and the voltage at plate pin 2 will be reduced essentially to ground. During the time that the positive gate signal is applied to V5014, the lower plate of C5052 will be clamped at ground potential. Now, by omitting V5012 and tying the upper end of R5052A to B+, we have the basic vacuum-tube sawtooth generator circuit. It is composed of V5011A and the R-C circuit, which includes C5052, R5052A, R5052B, R5053, R5054, and R5055.

Switch tube V5011A is normally conducting heavily. Current is cut off when the negative gate is applied to grid pin 1. C5052 will then charge toward the B+ voltage through the resistors in the plate circuit of the tube. This will produce an exponential rise in the voltage at plate pin 2. This exponential sweep voltage would not be linear.



SIMPLIFIED "A" SWEEP GENERATOR

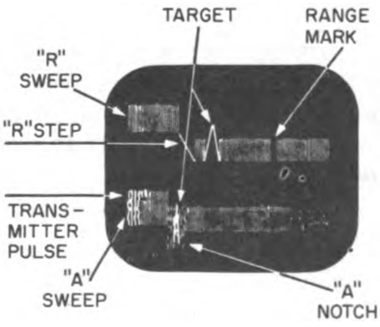
DISCHARGE CURRENT PATH FOR C5052

267.—"A" sweep generator circuits.

When the signal on grid pin 1 becomes positive, the tube will conduct and C5052 is discharged. Notice the discharge path for this capacitor. It is from the lower plate through V5016B to ground, and then through V5011A to the other plate of the capacitor. A sweep voltage has been produced that has a duration equal to the negative portion of the square wave at the grid of V5011A. This is the duration of the "A" sweep, the longer of the two sweep waveforms that are to be produced. More capacitance was used in this circuit than will be necessary in the generation of the "R" sweep.

The amplitude of the "A" sweep is controlled by adjustment of R5052, "A" SWEEP SPEED.

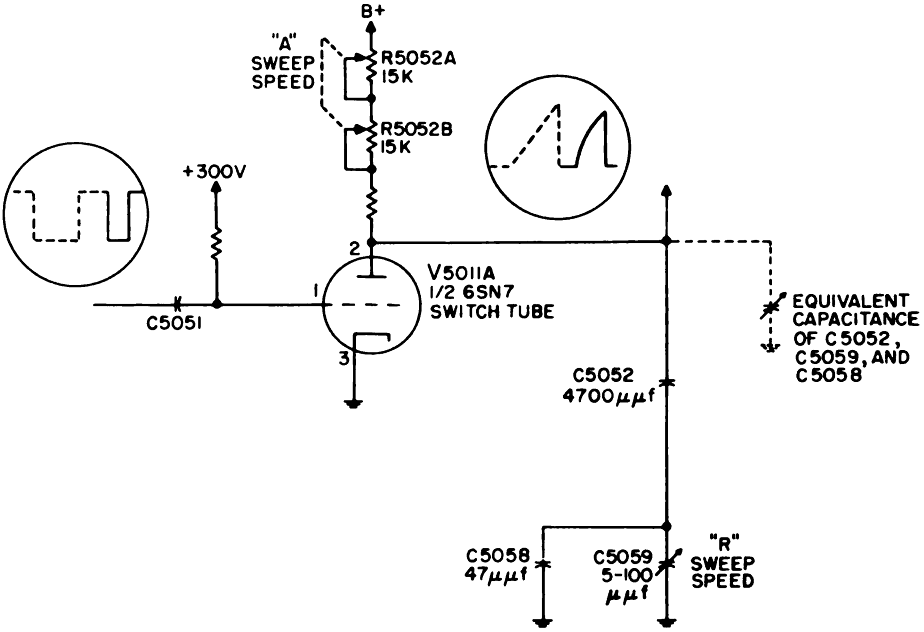
Immediately after the "A" sweep is produced on the A/R indicator, an "R" sweep is produced. The persistency of the indicator tube makes both of the sweeps visible at the same time.



268.—A/R indicator.

Applications (Continued)

Consider next that the "R" sweep gate is applied to the grid of V5011A. During this time, there is no positive voltage applied to the grids of V5014 and this tube is cut off. The capacitance that is now in the sawtooth generator circuit is C5052 (4700 μμf) in series with the parallel combination of C5058 (47 μμf) and C5059 (variable from 5 to 100 μμf). The equivalent capacitance is small and is variable from near 50 μμf to slightly less than 150 μμf. The negative "R" sweep gate at the grid of V5011A is of short duration. During the gate, tube current for V5011A will be cut off and the capacitance in the R-C circuit will charge toward B+ through the plate load resistors. The voltage at plate pin 2 of V5011A rises along the exponential curve. This exponential voltage rise continues for the duration of the "R" sweep gate and an "R" sweep waveform is produced. At the end of the negative gate, V5011A goes back into conduction and the capacitors are discharged through the tube.



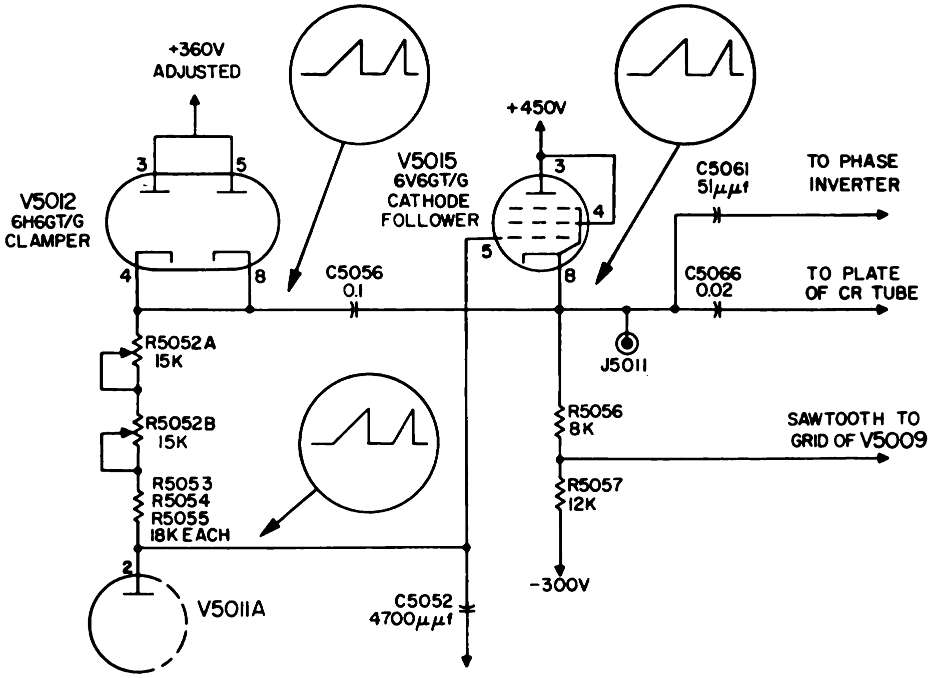
269. —Simplified "R" sweep generator.

C5059, "R" SWEEP SPEED, provides for adjustment of the amplitude of the "R" sweep waveform. By this adjustment, the "R" sweep length on the A/R indicator can be made to be correct. The "A" SWEEP SPEED control is adjusted only to control the length of the "A" sweep on the indicator.

Applications (Continued)

Let us study the remainder of the circuit to learn how linearity of the sweep waveforms is obtained. V5015 is a cathode follower; you are familiar with its operation. C5056 is a feedback capacitor. The voltage at cathode pin 8 of V5015 is fed back to cathode pins 4 and 8 of V5012. This tube functions as a clamper and clamps the voltage at its cathodes to the +360-volt level at the beginning of each sweep.

Plate pin 2 of V5011A is connected directly to grid pin 5 of V5015. As the capacitor (or capacitors) in the R-C circuit is being charged, the plate potential of V5011A rises. The control grid of V5015 will be at the same potential and have the same rise in voltage. Cathode pin 8 of V5015, because of cathode follower action, rises at the same rate. This rise in voltage at the cathode of V5015 is coupled through C5056 to the cathodes of V5012. The cathode potential of V5012 rises above the 360 volts on the plates of the tube.

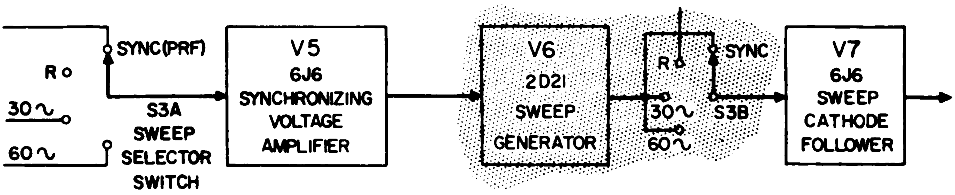


270.—Feedback circuit for linearity in charging path of capacitance.

What effect is this feedback voltage having on the charge current for the R-C circuit? As the lower end of the resistor-charging network, at plate pin 2 of V5011A, goes positive, the upper end of the network, cathode pins 4 and 8 of V5012, goes positive by an equal amount. The voltage across R5052A, R5052B, R5053, R5054, and R5055 remains constant. A constant voltage across this resistor network means that the current through the network will remain constant. This constant charge current will linearly charge the sweep capacitor (or capacitors) and will produce linear sweeps.

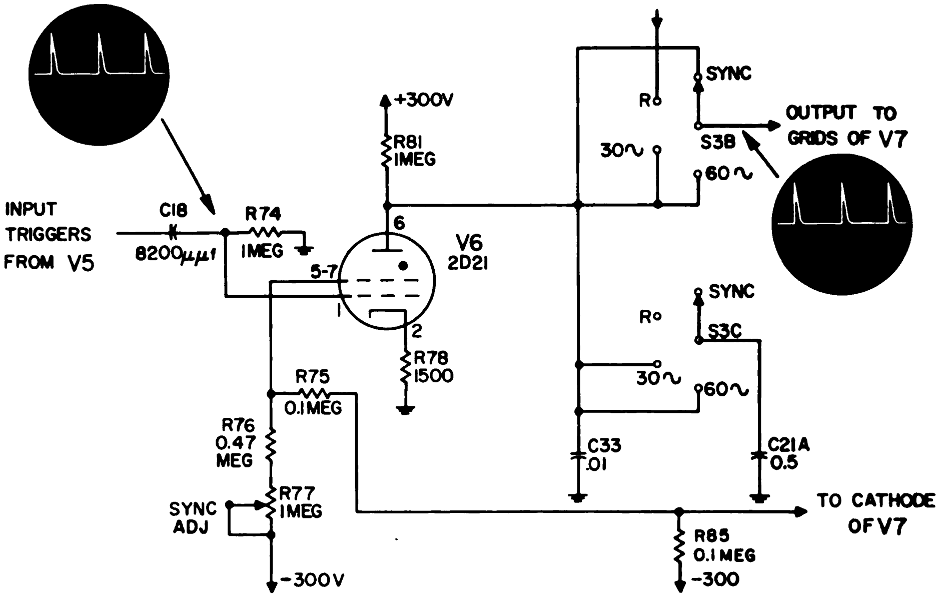
Applications (Continued)

An example of the use of a thyratron sawtooth generator is found in the Test Oscilloscope of Radar Equipment Mark 25 Mod 3. The Test Oscilloscope is used for the observation of waveforms throughout the equipment.



271.—Use of sweep generator in Mark 25 Radar Test Oscilloscope.

Because a tetrode-type tube is used in this thyratron sawtooth generator, it is different from the basic one that you studied. By using the tetrode, it is possible to apply a sufficiently negative voltage to the second control grid, so that the tube will not conduct on each trigger pulse applied to the other control grid. This provides for better analysis of some of the waveforms, as two or three complete waveforms may be viewed on the horizontal sweep. The adjustment of the negative voltage to the second control grid will control the number of waveforms available.



272.—Sweep generator circuit in Mark 25 Radar Test Oscilloscope.

Applications (Continued)

The input trigger to grid pin 1 of V6 will be selected by sweep selector switch, S3, and will be at the PRF, 30 cycles or 60 cycles. When the voltage at the plate has risen to the potential that a trigger will cause the tube to conduct, current will flow, discharging C33. Plate voltage will be reduced to the de-ionization level and current flow will cease. C33 then charges toward B+ and the exponential rise develops the sweep waveform. When the plate voltage rises sufficiently, there will be a trigger on the first control grid that will cause the tube to fire again and another sweep waveform will be developed.

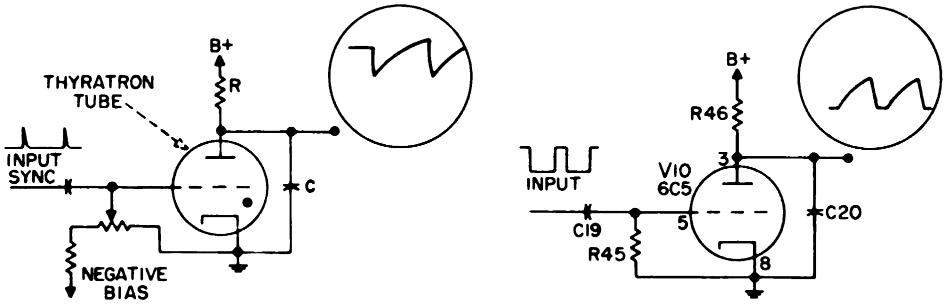
The 30-cycle and 60-cycle sweep waveforms have a much longer duration than the other sweeps. Additional capacitance is switched into the circuit when these two waveforms are being produced. C21A is added in parallel with C33 to improve linearity of these sweeps and to prevent wide variations in sweep length as different sweeps are used.

R77, SYNC ADJ, controls which trigger, applied to the first control grid, will cause this gas tube to fire. Without triggers applied, this sawtooth generator would be free-running at a frequency determined by the R-C time constant in the charging path of C33 and the firing potential of the tube.

Review

The sawtooth generator circuit is one which you have been using in all of your work that required use of an oscilloscope. Some of the important points about this circuit that will help you when you encounter it in fire control radar equipments are listed below.

1. Sawtooth generator circuits are used to develop the range sweeps in fire control radars.
2. The output of a sawtooth generator is the integrator output, the voltage taken from across the capacitor in an R-C circuit.
3. The two general types of sawtooth generators are those using a gas-type tube and those using a vacuum tube to control switching action.



273.—Sawtooth generator—review diagram.

Review (Continued)

4. A thyratron sawtooth generator may be free-running or synchronized to a trigger frequency.

5. Control of the free-running frequency may be obtained by changing the time constant in the R-C circuit.

6. The important control factor in a gas-type sawtooth generator is the ionization, or firing, potential of the gas tube.

7. It is essential that the range sweep for a radar indicator contain a high degree of linearity.

8. To improve linearity in the sweep waveform, only a small portion of the beginning of the exponential voltage rise is used.

9. Changing the R-C time constant in a vacuum-tube sawtooth generator will change the amplitude of the sawtooth waveform.

10. Sawtooth generators are used in the ranging circuits of some fire control radar equipments as one of the controlling voltages that are used to develop a precise range measuring pulse.

11. The linearity of a sawtooth waveform may be improved by increasing the R-C time constant.

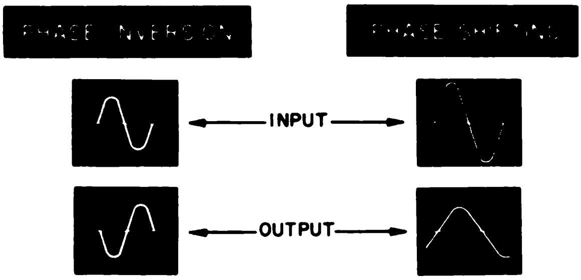
12. A linear sweep waveform may be generated by using a feedback circuit in a sawtooth generator.

Notes

TOPIC 13: PHASE-SHIFTING CIRCUITS

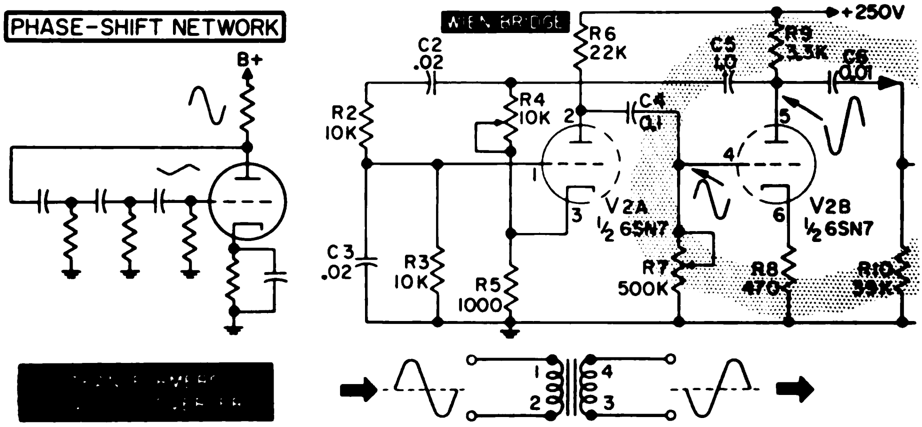
General Information

In this topic, you will study phase inverters and phase shifters. As the name implies, a phase inverter is a circuit that inverts, or reverses, the phase of the output signal in reference to the input signal. The phase difference between the output and input signals is 180 degrees; the two signals will be opposite in polarity. The phase shifter is a circuit that shifts the output signal in relation to the input signal, so that the phase relationship between the two signals is other than 180 degrees.



274. —Phase-inverted and phase-shifted waveforms.

You have already encountered these two types of circuits many times. V2B in the Wien bridge oscillator functioned as an amplifier and a phase inverter. All amplifier tubes invert the phase of the input signal. T2 in the blocking oscillator circuit in the chassis inverted the phase of the trigger pulse to the control grid of V6B. In multivibrators, you learned that the signal taken from the plate of one section was opposite in polarity to the signal taken from the other plate. In the phase-shift oscillator, you saw how three or four R-C circuits were used to obtain a total phase shift of 180 degrees. A combination of several R-C or several R-L circuits may be used to obtain any desired phase shift.



275. —Typical phase-shifting and phase-inversion circuits.

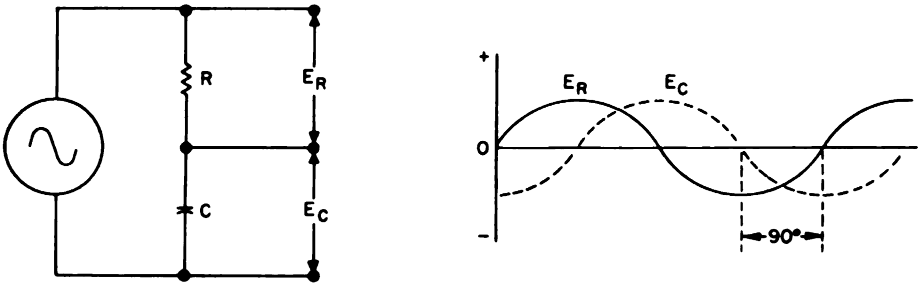
You will encounter phase-shifting circuits in the ranging, indicating, and power supply systems of fire control radar equipments.

Phase-Splitting Circuits

Another name encountered in connection with phase-shifting circuits is the phase splitter. The phase-splitting circuit is one that produces, from the same input, two output waveforms that differ in phase from each other.

Two types of circuits used for producing two out-of-phase voltages from the same input are the R-C phase-splitting circuit and the R-L phase-splitting circuit.

In the R-C circuit given below, notice that R and C are connected in series and represent the load impedance. The same current flows through both R and C. The voltage across R is always in phase with the current in it since, in a resistive circuit, the current and the voltage are in phase. In a capacitive circuit, the current and voltage are 90 degrees out of phase, with the current leading. Therefore, the voltage across C is 90 degrees out of phase with the current. Thus, the two voltages (that across C and that across R) are 90 degrees out of phase with each other.

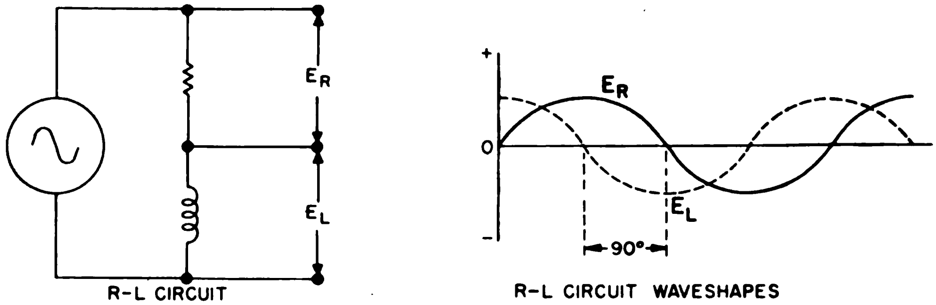


R-C CIRCUIT

R-C CIRCUIT WAVESHAPES

276.—R-C phase-splitting circuit.

In the R-L circuit, R and L are connected in series and are the load impedance for the generator. A similar phase shift occurs in this circuit. The big difference is that the voltage across R lags the voltage across L by 90 degrees. The voltage across R will be in phase with the current that produces it. The voltage across L leads the current by 90 degrees. Thus, the two voltages (that across L and that across R) are 90 degrees out of phase with each other.



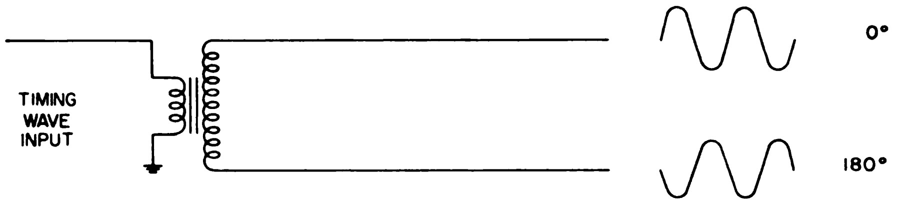
R-L CIRCUIT

R-L CIRCUIT WAVESHAPES

277.—R-L phase-splitting circuit.

Phase-Splitting Circuits (Continued)

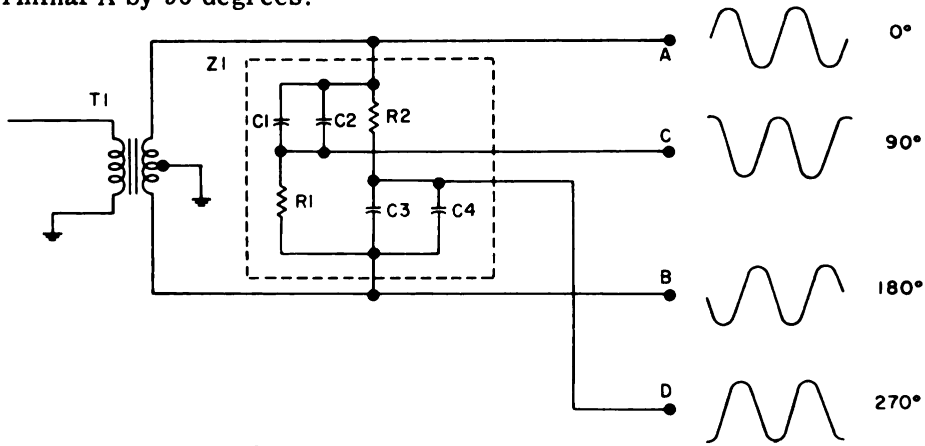
Phase-splitting circuits are required in the ranging systems of fire control radar equipments. In some radars the inputs for the phase-shift capacitor are four signals at the frequency of the timing wave, and these signals are separated by a phase angle to 90 degrees. The four required signals have phase angles of 0 degrees, 90 degrees, 180 degrees, and 270 degrees. Signals of 0 degrees and 180 degrees are readily obtained from a simple phase-inverter circuit, such as a transformer.



278. —Transformer phase- inverter.

The combination of a transformer and two R-C phase shifters may be used to split the original signal into the four required signals. Transformer T1 will produce signals at A and B that are 180 degrees out of phase with each other. These are two of the required signals. These two signals also are used as the input to the phase-shifting network, Z1. In Z1, the R-C phase-shifting circuit composed of C1, C2, and R1 produces a signal at C that leads the signal at A by 90 degrees. Since the signal at A has a phase angle of 0 degrees, the signal at C will have a phase angle of 90 degrees. The phase-shifting circuit composed of C3, C4, and R2 produces at D a signal that leads the signal at B by 90 degrees. Since the signal at B has a phase angle of 180 degrees, the signal at D will have a phase angle of 270 degrees. The parallel capacitors are of a value that offers a reactance at the timing wave frequency which is equal to the resistance of the resistors.

It should be noted that the waveforms shown in the following illustration are in relation to the center-tap of transformer T1, and that the phase-shifting networks are connected across the transformer winding. Due to this configuration, a voltage that lags terminal B by 90 degrees will also lead terminal A by 90 degrees.



279. —Phase-shifting networks.

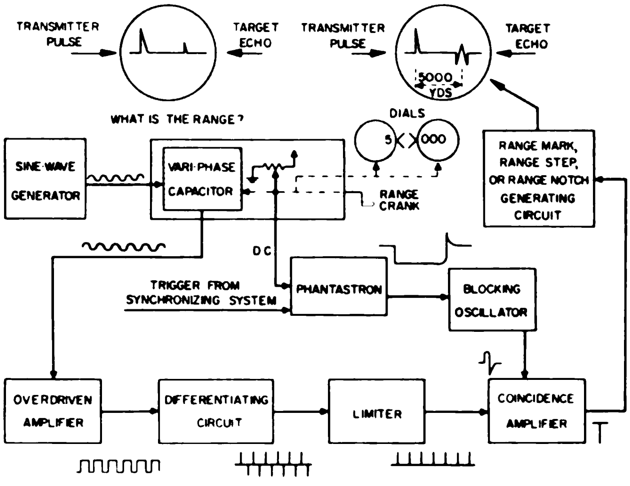
The transformer and the phase-shifting network are used to produce the required signals. These signals then are used as the inputs to the four stator plates of the phase-shift capacitor.

Phase-Shift (Vari-Phase) Capacitor

In fire control radar equipments, it is necessary that the ranging circuits be designed so that target range can be accurately determined. This is important because the range determined by the radar is used to establish the angular amount that the guns must lead the target in order to obtain hits.

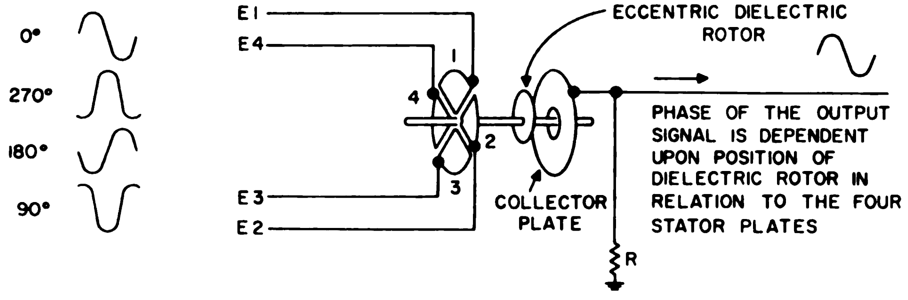
You have already studied the phantastron circuit which produces a very linear delay for ranging purposes. However, the time of occurrence of the trailing edge of the phantastron gate is not sufficiently accurate for fire control purposes. The length of the phantastron gate is usually considered to be the coarse range to the target.

The phase-shift (vari-phase) capacitor makes it possible to obtain the desired accuracy.



280. —Phase-shift (vari-phase) capacitor.

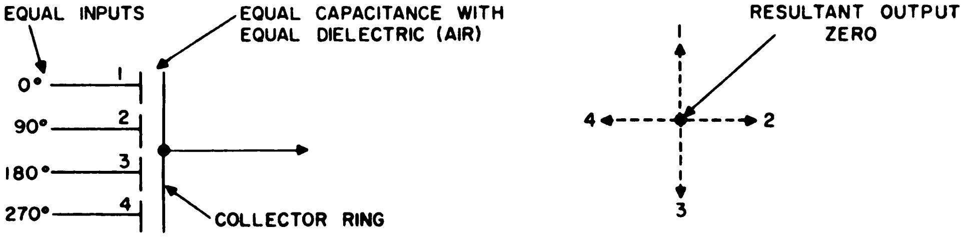
The output of the sine-wave generator is the timing wave and is applied to a phase-splitting network. The original signal is split into four phases which are 90 degrees displaced from one another and are of the same frequency. These four phases are applied one each to the plates of the vari-phase capacitor.


0°
270°
180°
90°
E1
E4
E3
E2
1
2
3
4
ECCENTRIC DIELECTRIC ROTOR
COLLECTOR PLATE
PHASE OF THE OUTPUT SIGNAL IS DEPENDENT UPON POSITION OF DIELECTRIC ROTOR IN RELATION TO THE FOUR STATOR PLATES
R

281. —Inputs to vari-phase capacitor.

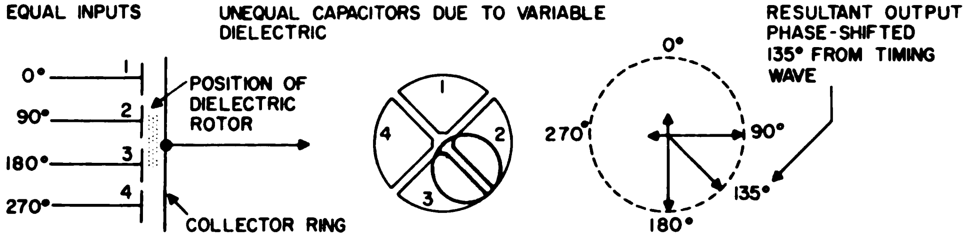
Phase-Shift (Vari-Phase) Capacitor (Continued)

The phase-shift capacitor is essentially four capacitors in parallel. The inputs to these four capacitors are of equal amplitude and are of the phase indicated on the diagram. If the capacitance of the capacitors is equal, there will be no output signal.



282. —Phase-shift capacitor with zero output.

These four capacitors are made variable by the rotation of the dielectric rotor. From the diagrams, you can see that the area of the rotor is only slightly larger than the area of one plate. With equal area of the rotor over stator plates 2 and 3 and a very small area of the rotor over plates 1 and 4, the phase of the output signal will be 135 degrees. The vector diagram shows how the phase of the output signal can be determined.


EQUAL INPUTS
UNEQUAL CAPACITORS DUE TO VARIABLE DIELECTRIC
RESULTANT OUTPUT PHASE-SHIFTED 135° FROM TIMING WAVE
0°
90°
180°
270°
1
2
3
4
POSITION OF DIELECTRIC ROTOR
COLLECTOR RING
1
2
3
4
0°
270°
90°
135°
180°

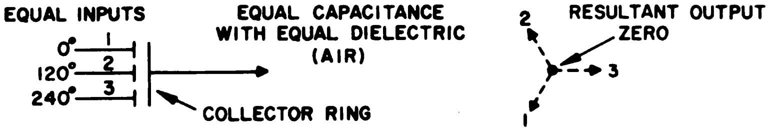
283. —Phase-shift capacitor with output shifted 135 degrees.

In fire control radars, the range handcrank, or the range motor, is connected mechanically to the phase-shift capacitor. As the handcrank, or motor, is rotated, the dielectric rotor of the phase-shift capacitor is rotated. This causes the phase of the a-c voltage that appears on the collector plate to be phase-shifted from the original timing wave from the sine-wave generator. The amount of phase shift is dependent upon the position of the dielectric rotor relative to the four input plates. The frequency of the sine-wave generator is usually one that has a period time of 6.1 microseconds. Note that the period time is equal to 1000 yards.

Since the rotor can be at any position in its 360 degrees of rotation, the phase-shift capacitor can select any phase of the voltage from 0 degrees through 360 degrees. Its output phase will be shifted from the sine-wave generator by an amount which will correspond to some portion of 1000 yards (6.1 microseconds, the time of one cycle of the input signal). The output voltage is amplified, distorted, differentiated, and limited so that there will be only a series of pulses that occur every 6.1 microseconds. Since the sine wave can be phase-shifted (moved), the resulting pulses can be used to select any radar time within any 0- to 1000-yard interval.

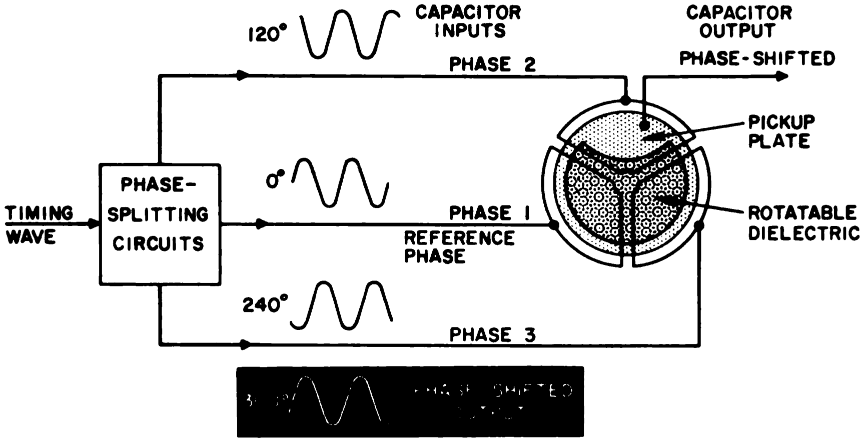
Phase-Shift (Vari-Phase) Capacitor (Continued)

In some radar equipments, a three-stator phase-shift capacitor is used. Except for its physical construction and the input signals, the operation of this capacitor is the same as the four-stator capacitor. It requires three input signals separated by a phase angle of 120 degrees. These signals can be readily obtained from the timing wave by fixed phase-shifting networks.



284.—Three-stator phase-shift capacitor with zero output.

This phase-shifting capacitor is made up of three insulated plates (each a 120-degree segment of a circle). These stator plates are mounted in the same plane and are separated from a circular pickup plate by a fixed distance. A shaft passes through the pickup plate and is perpendicular to the three stator plates. This shaft is connected to the dielectric. The dielectric is free to rotate in the space between the three segments and the circular pickup plate. The rotatable dielectric serves to vary the capacitance between the circular pickup plate and each of the three segments. Rotation of the dielectric changes the capacitance between the pickup plate and each of the segments by changing the dielectric constant. The dielectric rotor has a high dielectric constant and, as it is rotated, the dielectric constant is changed from that of air to this high dielectric constant; or it is changed from that of the high dielectric constant to that of air.

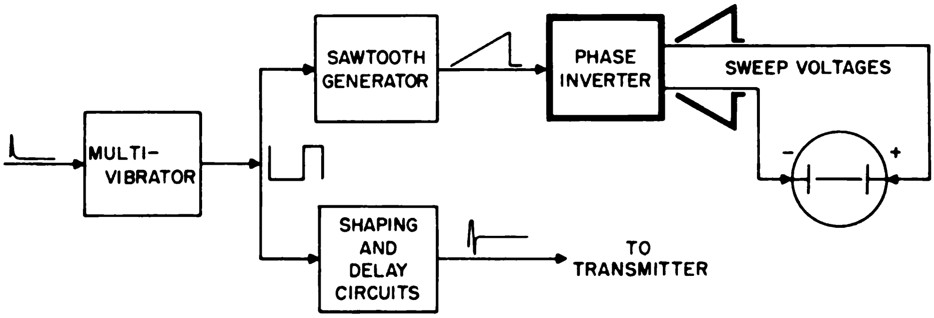


285.—Three-stator phase-shift capacitor with shifted output.

The phase shift between the voltage on the pickup plate and the reference phase is always proportional to the mechanical rotation of the shaft that is attached to the dielectric rotor. The shaft is connected through gears to the range dials. Rotation of the shaft will shift the phase of the output signal by an amount equal to the rotation and will change the range dial reading a proportionate amount.

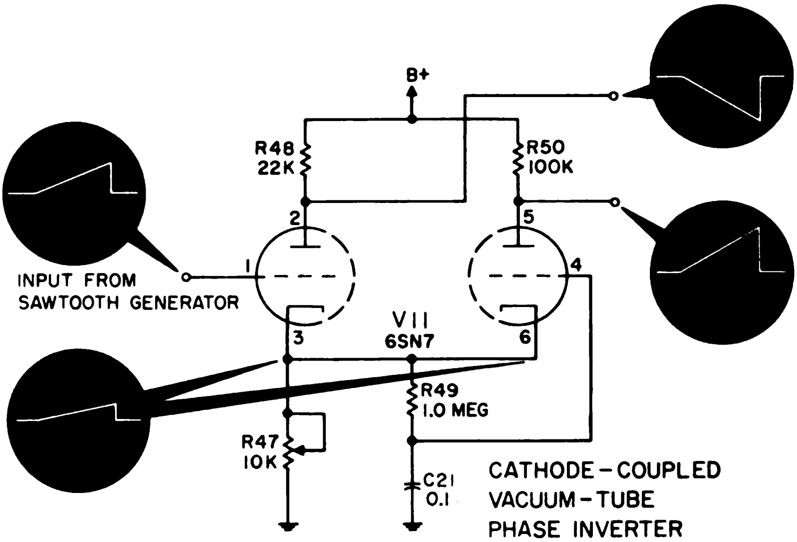
The Vacuum-Tube Phase Inverter

A vacuum-tube phase inverter is used in the indicating system of some fire control radars to obtain two signals 180 degrees out of phase for application to opposite deflection plates of the indicator tubes. This provides push-pull signals to the deflection plates. The output of the sawtooth generator may be coupled to a phase inverter. The two outputs of the phase inverter are connected to opposite deflection plates of the CR tube and produce the desired sweep trace.



286.—Use of vacuum-tube phase inverter in indicating system.

The diagram below shows the phase inverter with which you will experiment. With no input applied to the circuit, both stages are conducting, causing a positive voltage to be developed across the common cathode resistor. This voltage has no biasing effect on V11B since its grid is connected to the cathode through the 1-meg resistor. The grid of V11A is connected directly to the plate of the sawtooth generator and is very close to ground potential when no sweep is developed. Therefore, V11A has some negative bias, because of the drop across the cathode resistor.



B+
R48 22K
R50 100K
2
5
1
4
INPUT FROM SAWTOOTH GENERATOR
3
6
V11 6SN7
R49 1.0 MEG
R47 10K
C21 0.1
CATHODE-COUPLED VACUUM-TUBE PHASE INVERTER

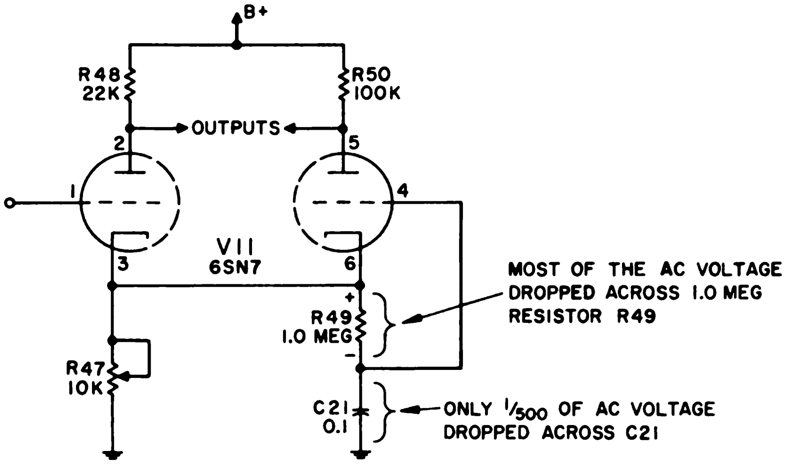
287.—Cathode-coupled vacuum-tube phase inverter (I).

The Vacuum-Tube Phase Inverter (Continued)

When a voltage waveform is applied to the grid of V11A, it causes the tube to act as an amplifier and cathode follower at the same time. Since the cathode resistor is unbypassed, the voltage at the cathode will have the same phase as that on the grid, with slightly decreased amplitude. The waveform at the plate of V11A will be increased in amplitude by the amplifying action of the tube, although the tube cannot amplify with maximum efficiency because of the degenerative effect of the unbypassed cathode resistor.

No a-c fluctuation appears between the grid of V11B and ground because the grid is at a-c ground potential due to the 0.1-mfd capacitor. This means that the cathode-to-ground, a-c potential of V11A, actually appears between the cathode and the grid of V11B. Some d-c bias voltage is developed in V11B because of the grid current being drawn by the tube.

To see how the grid of V11B is effectively at a-c ground potential, consider the 1-meg resistor (R49) and the 0.1-mfd capacitor (C21) as a voltage divider in parallel with the common cathode resistor. Most of the a-c voltage developed across R47 will be dropped across the 1-meg resistor, while very little (1/500th) is dropped across the capacitor, which has a reactance of only about 2000 ohms at 800 cycles. The a-c potential to ground of grid pin 4 is this very small voltage, which is negligible.


B+
R48
22K
R50
100K
OUTPUTS
2
5
1
4
V11
6SN7
3
6
+
R49
1.0 MEG
−
R47
10K
C21
0.1
MOST OF THE AC VOLTAGE DROPPED ACROSS 1.0 MEG RESISTOR R49
ONLY 1/500 OF AC VOLTAGE DROPPED ACROSS C21

288. — Cathode coupled vacuum-tube phase inverter (II).

By proper choice of the resistance values in the plate and cathode circuits, the output voltages of both sections of the tube can be made equal. R47, the common cathode resistor, is variable, while the two plate-load resistors are of fixed values. The resistance of the common cathode resistor can be set to a value that will give equal amplitudes of the output voltages at the two plates. The phase difference of the two output voltages will be 180 degrees.

PHASE-SHIFTING CIRCUITS

Experiment—Checking Waveforms

For this experiment you will need V11 (6SN7) and an oscilloscope.

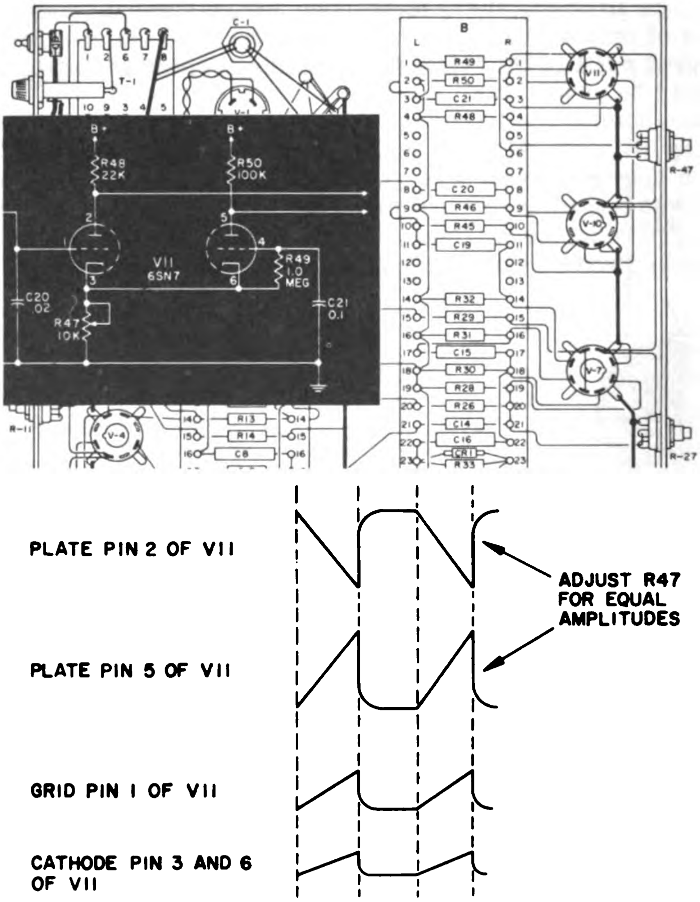
1. Balance the outputs of V11, with the oscilloscope probe alternately connected to plate pins 2 and 5, by adjusting R47 until the two waveforms are of equal amplitude.

2. Observe the waveforms.

   a. Note that the signals at the two plates are 180 degrees out of phase.

   b. Note that the waveform at grid pin 1 is of the same phase as the waveform at cathode pins 3 and 6. Can you explain why the waveform at the cathode is of less amplitude than the waveform at grid pin 1?

   c. Note that no waveform appears when the 'scope probe is connected to grid pin 4.



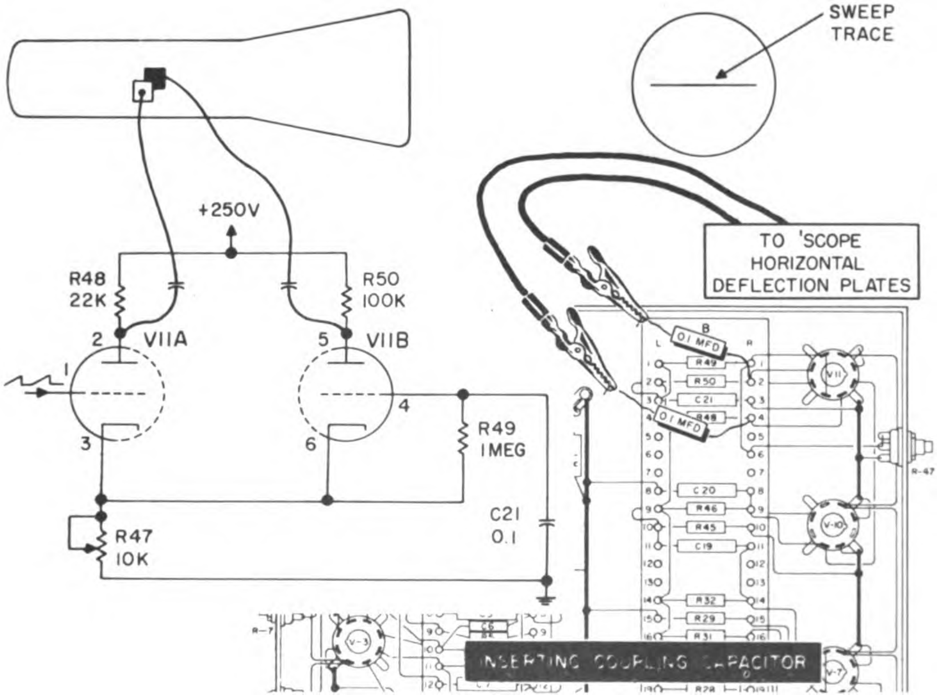
289.—Phase-shifting circuits—checking waveforms.

Experiment—Using Output as Sweep for 'Scope

You are now going to apply the sawtooth push-pull output from the phase inverter through capacitors to the horizontal deflection plates of the oscilloscope to obtain a sweep.

For this experiment, you will require an oscilloscope and two 0.1-mfd capacitors rated at 400 vdcw.

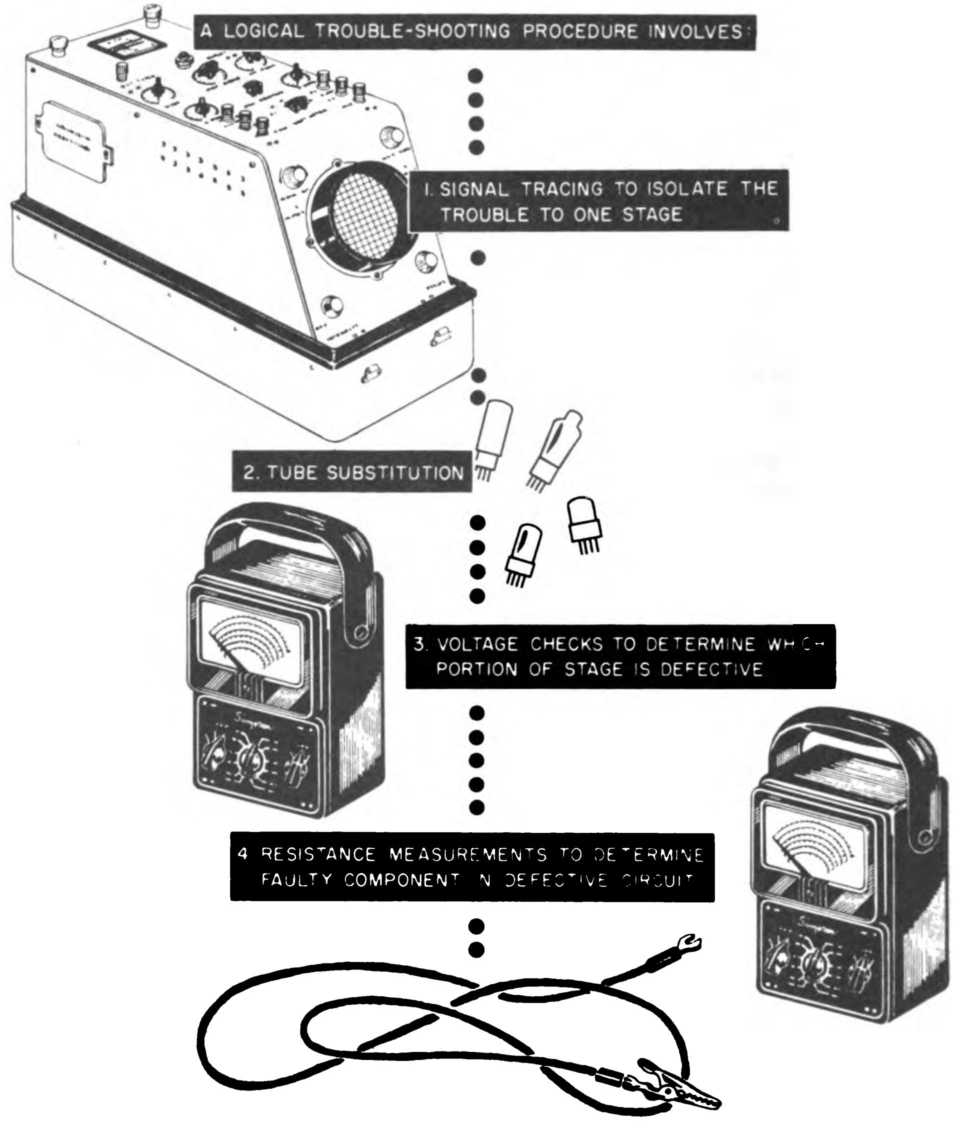
1. Connect a 0.1-mfd capacitor to each plate by soldering one capacitor to plate 2 (B-4R) and the other to plate 5 (B-2R). Attach alligator clip leads between the other ends of the capacitors and the horizontal deflection plates. Your instructor will tell you how to get to the 'scope deflection plates.
2. Apply power to the 'scope, and adjust the intensity and centering controls. You will note that no sweep is being produced by the 'scope and that only a dot is visible.
3. Apply power to the chassis; then note that the dot is now being deflected across the face of the 'scope and is producing a sweep trace.
4. Vary the setting of R47 and note that the sweep centering is affected.
5. Secure power to the chassis and oscilloscope. Remove the two capacitors. The circuit has now been returned to normal.



290. —Phase inverter—obtaining sweep voltage.

Experiment—Trouble Shooting

Because the cathode-coupled phase inverter is an amplifier, trouble shooting it is a matter of tracing the input signal through the circuit until it disappears or is distorted. At this point, voltage and resistance measurements are made to find the faulty component.

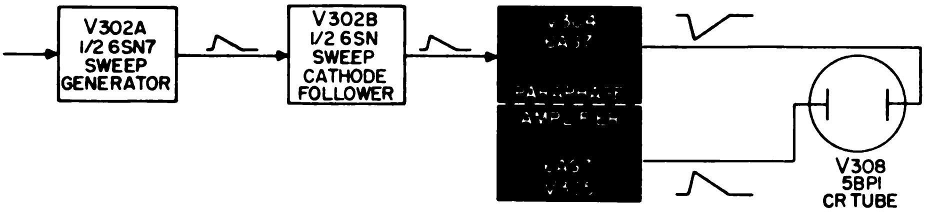

A LOGICAL TROUBLE-SHOOTING PROCEDURE INVOLVES:
1. SIGNAL TRACING TO ISOLATE THE TROUBLE TO ONE STAGE
2. TUBE SUBSTITUTION
3. VOLTAGE CHECKS TO DETERMINE WHICH PORTION OF STAGE IS DEFECTIVE
4 RESISTANCE MEASUREMENTS TO DETERMINE FAULTY COMPONENT IN DEFECTIVE CIRCUIT

291. —Phase inverter—trouble shooting.

You and your partner will now insert troubles into each other's chassis and service them, using a logical procedure. If you wish to insert a defective component elsewhere in the chassis, request it from your instructor. He has a supply of bad parts on hand.

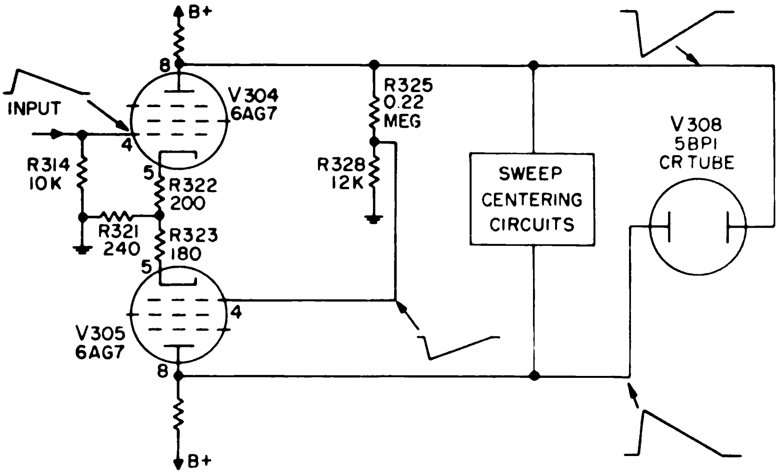
Applications

Several examples of phase inverters and phase shifters will be given. The first example is from Radar Equipment Mark 34. This phase-inverter circuit uses two tubes and associated circuits to obtain two sweep waveforms that are of equal amplitude but are 180 degrees out of phase. The two waveforms are applied to the horizontal deflection plates of the radar indicator tube to provide the horizontal sweep trace.



292.—Use of phase inverter in Mark 34 Radar.

The input signal to grid pin 4 of V304 is the sawtooth sweep waveform. This signal is amplified and inverted in this tube. Its output is coupled to the right deflection plate of the CR tube, V308. The output of V304 is developed across the voltage divider, composed of R325 and R328. That portion of the output of V304 which is developed across R328 is applied to grid pin 4 of V305. This tube amplifies and inverts its input waveform. Its output is applied to the left deflection plate of the CR tube. The sweep waveform is applied in push-pull to the horizontal deflection plates of the indicator tube. At the beginning of the sweep, the voltage on the left deflection plate goes positive, pulling the electron beam to the left; and the voltage on the right deflection plate goes negative, pushing the electron beam to the left. The two sweep voltages then begin to change in amplitude; the one on the left plate goes in a negative direction as the voltage on the right deflection plate goes in a positive direction. These two changing voltages cause the electron beam to move from left to right across the face of the CR tube, producing the horizontal sweep trace.

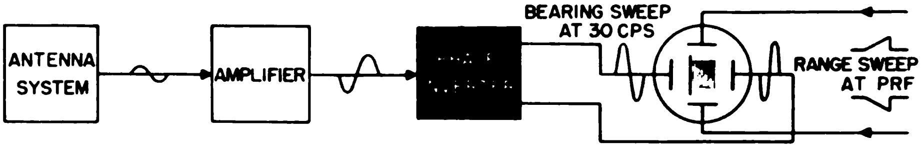


293.—Phase inverter circuit (simplified) in Mark 34 Radar.

Applications (Continued)

The phase inverter shown on this page is a type that will be encountered in Fire Control Radars Mark 25 Mod 3 and AN/SPG-48.

The input to this circuit is a 30-cycle voltage from the antenna. The 30-cycle output voltage is applied to the radar indicators, and provides a means by which the pointer or trainer may use the radar indicator to center the radar beam on the target.



294. —Use of phase inverter in Mark 25 and AN/SPG-48 Radars.

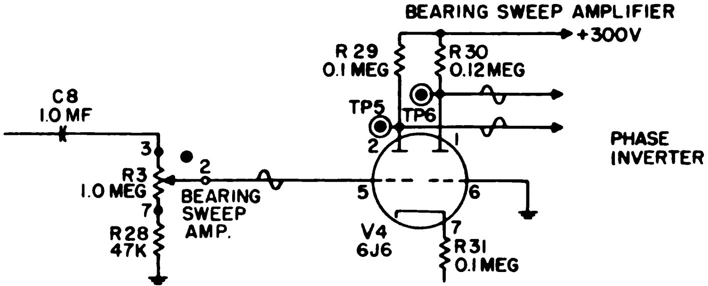
You will notice that the cathode is connected through a resistor to a -300 volt power supply, while the plate resistors are connected to a +300-volt supply. Observe also that one grid is connected into an R-C coupling circuit while the other is connected directly to ground.

When no signal is available, both halves of the tube will conduct and the cathode-to-ground potential will be very nearly zero.

Now, when the 30-cycle signal voltage drives grid 5 positive, the cathode will also go positive. The plate voltage at plate pin 2 will drop and some amplification of the signal will occur.

The action in the 1-6-7 section of the tube is just the opposite. Since grid pin 6 is fixed at ground, any change in tube current will cause the cathode-to-grid potential of this section to vary. Therefore, with a positive-going signal at grid 5, the cathode goes positive, which produces the same result as though grid pin 6 were driven negative. Thus, the output at plate 2 decreases while that at plate 1 increases. When the signal is negative, the voltage change at the plates will be reversed. This type of phase inverter is often referred to as a grounded-grid (or cathode-coupled) phase inverter.

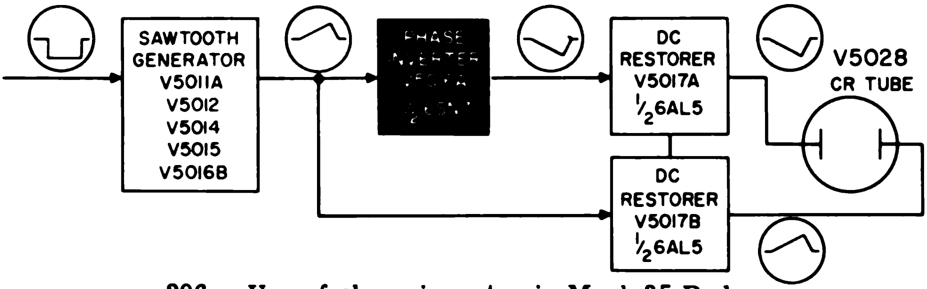
The circuit shown is the one in the bearing sweep channel. An identical circuit will also be encountered in the elevation sweep channel. R3 is used to obtain the proper amount of voltage change at the two outputs, TP5 and TP6.



295. —Phase inverter in Mark 25 Radar.

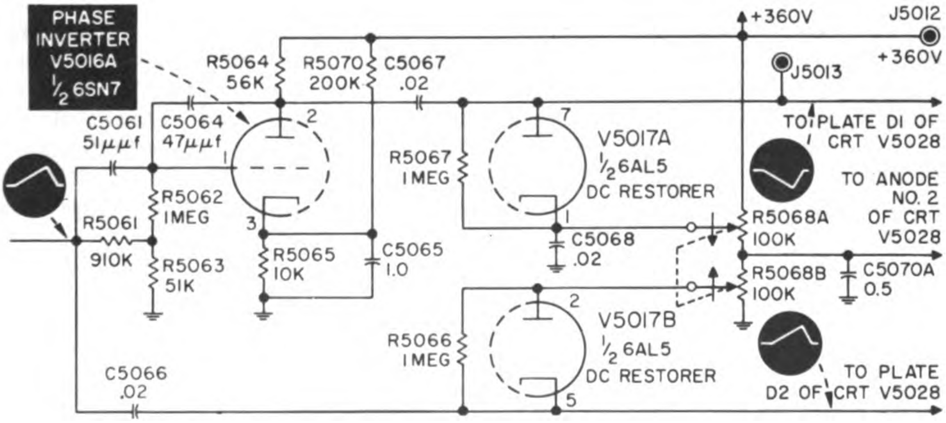
Applications (Continued)

Another example of a phase inverter is from Radar Equipment Mark 35. The circuit is in the indicating system of this radar. You have already encountered the circuits that precede and follow the phase inverter. Sweep-generating circuits precede it; you studied them in topic 12, "Sawtooth Generators." Immediately after the phase inverter are the biased clampers; you studied them in topic 7, "Clamping Circuits."



296.—Use of phase inverter in Mark 35 Radar.

V5016A, the phase inverter, reverses the polarity of the sweep waveform. It has a gain of unity, so that the sweep waveform may be applied in push-pull to the horizontal deflection plates of the CR tube in the radar indicator. The positive sawtooth waveform output of the sawtooth generator is applied through the coupling circuits to the grid of the phase-inverter tube, and to the cathode of the d-c restorer, V5017B. The coupling circuits in the grid of V5016A provide attenuation so that the output of V5016A, which is applied to the plate of the d-c restorer, V5017A, is equal in amplitude to the signal on the other d-c restorer.



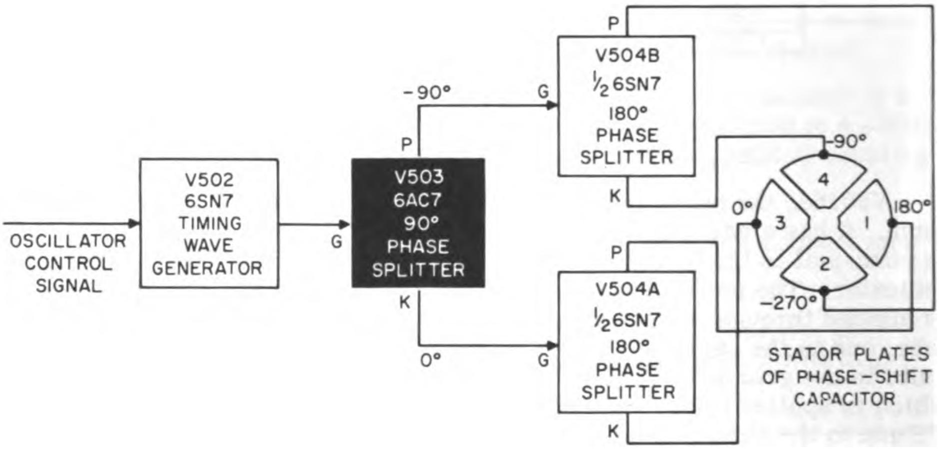
297.—Phase inverter and d-c restorers in Mark 35 Radar.

Negative feedback from plate to grid of V5016A through C5064 improves the linearity of the output of the phase inverter.

The biased clampers insure that successive sweeps will start at the same point on the face of the CR tube.

Applications (Continued)

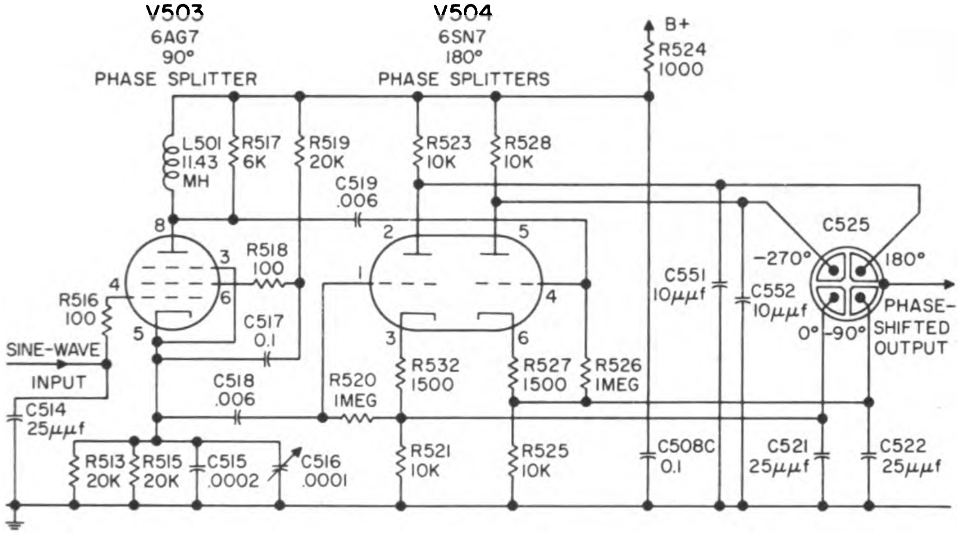
The next example covers phase-splitter circuits from Radar Equipment Mark 34 and Radar Set AN/SPG-34. These circuits are from the ranging systems of these equipments. The first phase splitter functions to produce two output signals from one input signal. The two output signals differ in phase by 90 degrees. These two voltages are fed to 180-degree phase-splitting stages that follow. An output voltage is taken from the cathode and plate of each of the tubes. The 0-degree signal is used to produce signals of 0 degrees and 180 degrees. The 90-degree signal is used to produce signals of 90 degrees and 270 degrees. In this manner, four signals of 0 degrees, 90 degrees, 180 degrees, and 270 degrees are obtained for use in the phase-shift capacitor circuit.


OSCILLATOR CONTROL SIGNAL
V502 6SN7 TIMING WAVE GENERATOR
G
V503 6AC7 90° PHASE SPLITTER
P
K
-90°
0°
G
P
V504B ½6SN7 180° PHASE SPLITTER
K
P
V504A ½6SN7 180° PHASE SPLITTER
K
-90°
0°
180°
-270°
4
3
1
2
STATOR PLATES OF PHASE-SHIFT CAPACITOR

298.—Use of phase splitters in Mark 34 and AN/SPG-34 Radars.

In a conventional vacuum-tube phase-splitting circuit, the signal taken from the plate is 180 degrees out of phase with the signal taken from the cathode. In V503, it is desired to have the voltage on the plate lag the voltage on the cathode by 90 degrees and to have these two voltages of equal amplitude. The phase relationship is accomplished by an inductive-resistive load in the plate circuit and a resistive-capacitive load in the cathode circuit. To obtain output signals of equal amplitude, the plate and cathode impedances must be equal.

Applications (Continued)



299.—Phase splitters in Mark 34 Radar.

If the plate impedance of V503 were pure inductance and the cathode impedance were pure resistance, the inductance would cause the plate voltage to lag the cathode voltage by 90 degrees. However, the plate inductor (L501) is not pure inductance, but contains distributed capacity and resistance. The distributed capacity would make the plate circuit resonant at some frequency. To prevent plate circuit oscillations, the inductance is shunted by resistance (R517). This shunt resistance reduces the phase angle of the plate impedance. To maintain the 90-degree lag in the plate voltage, the phase angle of the cathode voltage must be changed an equal amount. This is accomplished by shunting the cathode resistance (R513 and R515) by capacitance (C515 and C516) with reactance equal to the shunt resistance in the plate circuit. The output signals from V503 are the signal from the plate and the signal from the cathode. The plate signal has a 90-degree phase lag from the signal on the cathode.

PHASE-SHIFTING CIRCUITS

Review

Phase inverters, phase splitters, and phase-shifting circuits will be encountered many times in fire control radar equipments. They are found in all indicating and ranging systems of these radars.

Some important points to remember about these circuits are:

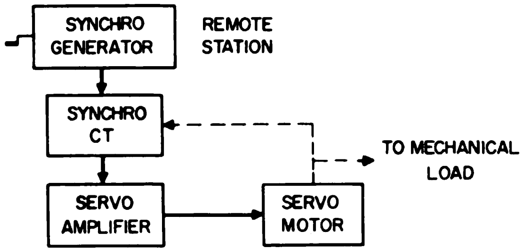
1. A phase inverter is a circuit that has an output signal opposite in polarity to the input signal.
2. A phase splitter produces, from one input signal, two output signals that differ in phase from each other.
3. A capacitive circuit produces a lagging phase shift of the output signal from the input signal.
4. An inductive circuit produces a leading phase shift of the output signal from the input signal.
5. R-L or R-C circuits may be used to shift the phase of a signal.
6. Three or more shifting sections may be used to produce the required 180 degrees of phase shift in the phase-shift oscillator.
7. A vacuum tube is used to provide the required 180 degrees of phase shift in a Wien bridge oscillator.
8. The phase-shift (vari-phase) capacitor makes possible the required range accuracy of fire control radar equipment.
9. The phase of the output signal from a phase-shift capacitor is determined by the position of the dielectric rotor.
10. A phase inverter provides the two signals 180 degrees out of phase that are used in push-pull circuits.
11. A phase inverter, either a vacuum tube or a transformer, is used to provide push-pull deflection in a radar indicator tube.
12. The phase shift produced by an R-C or an R-L circuit is determined by the values of components and the frequency of the applied signal.

Notes

TOPIC 14: ERROR DETECTING CIRCUITS

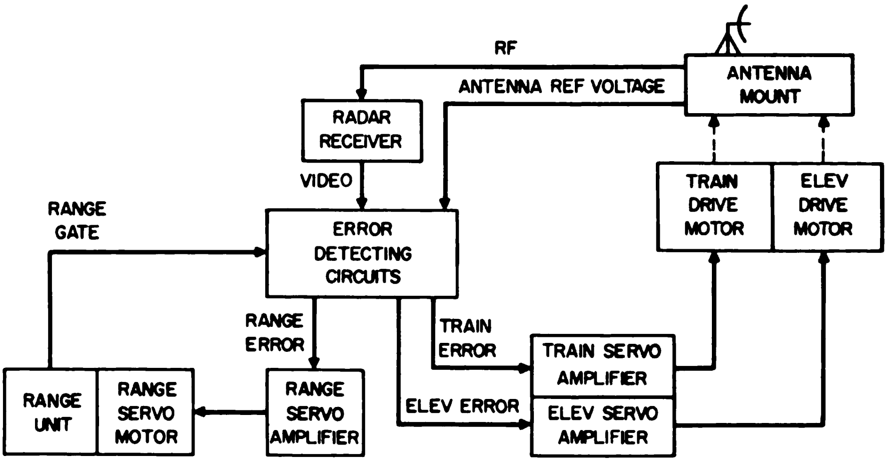
General Information

Automatic tracking systems for fire control radar equipments base their operation on error detecting circuits. These systems operate on the same principle as the servo systems that you will be studying soon. In a servo system, the error signal is the input to a servo amplifier. The output of the servo amplifier is the input to a servo motor which drives the servo system until the error has been eliminated.



300.—Basic error detector and servo loop.

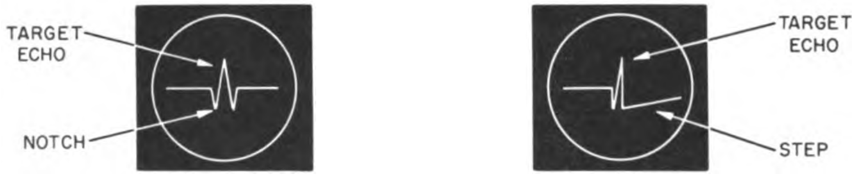
Once the radar target has been placed in or near the range gate, the automatic tracking servo loops may be put into operation. If the radar is not "on target" in range, there will be an error signal from the range error detecting circuits. This error signal is used to provide a voltage as the input to a range servo loop that drives the ranging circuits to take out the error signal. Likewise, if the radar antenna is not trained directly at the target, there will be an error signal output from the train error detecting circuits. This error signal is used to develop a voltage input for the train servo loop to drive the antenna mount until the error has been eliminated. If the antenna is not "on target" in elevation, the elevation error detecting circuits will determine the error in elevation. This error signal is used to develop a voltage as the input to the elevation servo loop to cause the antenna to be moved in elevation until the error has been eliminated.



301.—Typical radar error detectors and servo loops.

Range Determination

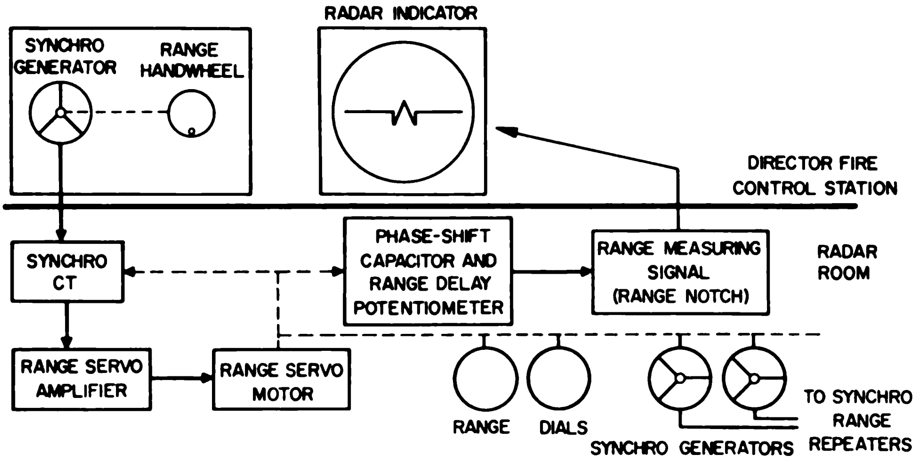
The position of the range notch, or the range step, on the range sweep and the time of occurrence of the range gate is determined by positions of the rotor of the phase-shift capacitor and the arm of the range delay potentiometer. Rotation of the range gears will change the position of the dielectric rotor of the phase-shift capacitor and the position of the arm of the range delay potentiometer. This will move the range notch, or range step, along the range sweep trace on the indicator. Also, this changes the reading of the range dials.



302.—"On target" indications in range.

To determine the range to a target that appears on the sweep on the indicator, the range gears are rotated until the target is centered in the range notch. If a range step is used, the gears are rotated until the target is against the left edge of the range step. The range to the target is then read on the range dials.

To determine the range to a moving target requires that the range gears be rotated so as to maintain the target echo centered in the range notch. This can be accomplished manually. The range operator in the director will look at his indicator presentation and determine which direction the range dials should be rotated. He will rotate his range handwheel, and the range servo system will have an error signal. The output from the CT will be the error signal. It will be used in the servo system to cause the rotor of the phase-shift capacitor and the arm of the range delay potentiometer to be rotated. This will result in the range notch being moved and the range dial readings being changed. Continued changes in thè range handwheel will be necessary to maintain an "on target" indication in range on the range operator's indicator.

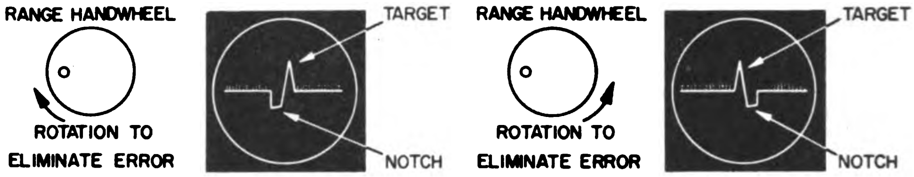

RADAR INDICATOR
SYNCHRO GENERATOR
RANGE HANDWHEEL
DIRECTOR FIRE CONTROL STATION
SYNCHRO CT
PHASE-SHIFT CAPACITOR AND RANGE DELAY POTENTIOMETER
RANGE MEASURING SIGNAL (RANGE NOTCH)
RADAR ROOM
RANGE SERVO AMPLIFIER
RANGE SERVO MOTOR
RANGE DIALS
SYNCHRO GENERATORS
TO SYNCHRO RANGE REPEATERS

303.—Manual tracking range servo.

ERROR DETECTING CIRCUITS

Range Error

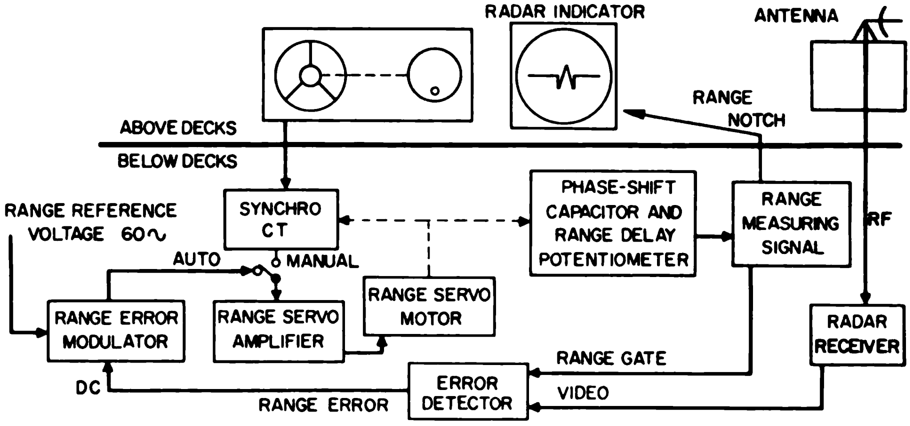
In a manual ranging system, the range operator is the range error detector. He observes the presentation on his indicator and compares the time of occurrence of the range notch and target echo (video). If a range error exists, he determines the direction of the error and rotates his range handwheel in a direction so that the range servo system will eliminate the error.



304.—Manual range error correction.

In an automatic tracking radar, the range error detector circuits perform the error detector function of the range operator. These circuits compare the time of occurrence of the target echo and the range gate. The range gate is used by these circuits in a manner similar to the range operator's use of the range notch. The notch is a visual signal and the gate is an electrical signal, not presented on the indicators.

The error detecting circuits determine if there is a difference in time of occurrence of the target echo and range gate. With no difference, there is no error signal. With a difference in time of the two signals, the direction of the time difference is determined. Is the range gate occurring before or after the target video? The error detecting circuits determine the direction of the error. The error signal, a positive or negative d-c voltage, is the input to a range error modulator. The modulator output is a 60-cycle signal that is in phase with or 180 degrees out of phase with the reference voltage. This signal is amplified in the servo amplifier and applied to the servo motor. The range gears will be driven in a direction to eliminate the error. The direction of rotation of the range gears is determined by the phase of the 60-cycle input to the servo motor, and the phase of this signal is determined by the polarity of the d-c error signal.



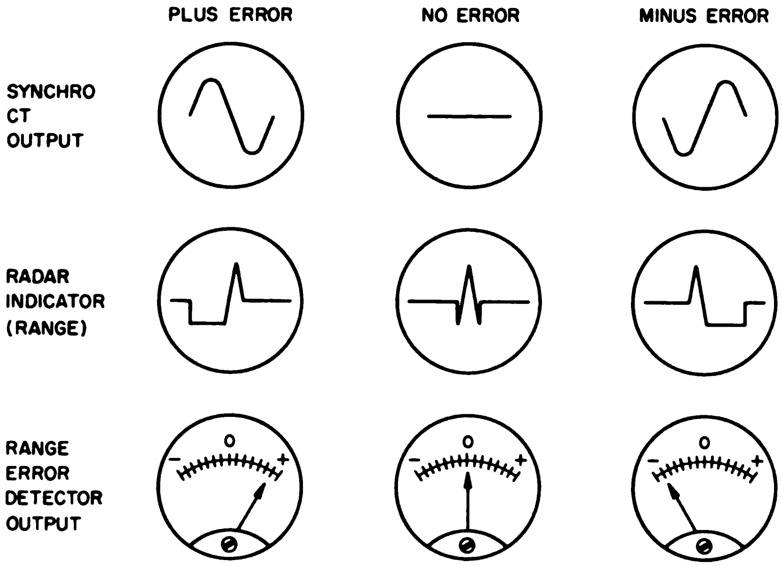
305.—Automatic tracking range servo.

Range Error (Continued)

In an error detecting system, it is necessary that three possible conditions will produce an output that can be utilized in a servo loop to remove the error. These three conditions are:

1. No error — No output.
2. An error in one direction — A definite output polarity.
3. An error in the opposite direction — The opposite output polarity.

You will recall that these are the same conditions you noted in your studies of Synchro and Servo Fundamentals.



306.—Range error indications.

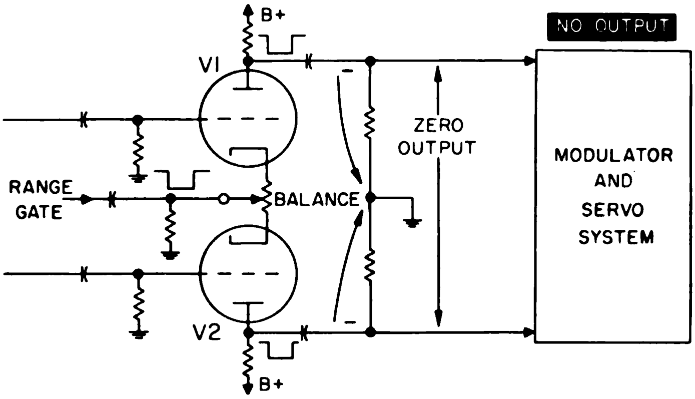
Range determination by radar, in automatic tracking, is essentially a comparison of the time relationship existing between a selected target echo (video) and the range gate. To produce voltages which will cause the range servo system to bring this time relationship to zero is the purpose of the range error detecting circuits. Since control of the video is not possible, it is necessary that the voltages produced be used to move the range gate.

The error detecting circuits utilize the video signal and the range gate to detect and produce the error voltage. Since the output is applied to a servo amplifier, it is required that the polarity of the output voltage can be reversed so that two directions of motion can be obtained at the servo motor.

To obtain the desired voltages, error detector circuits use several tube circuits. Some similarity to coincidence amplifiers may be noted in these circuits, and that is that both the range gate and video signals must be available at the tubes to produce error voltages. If no video is present, there is no range error voltage; if there is no range gate present, there is no range error voltage.

Range Error (Continued)

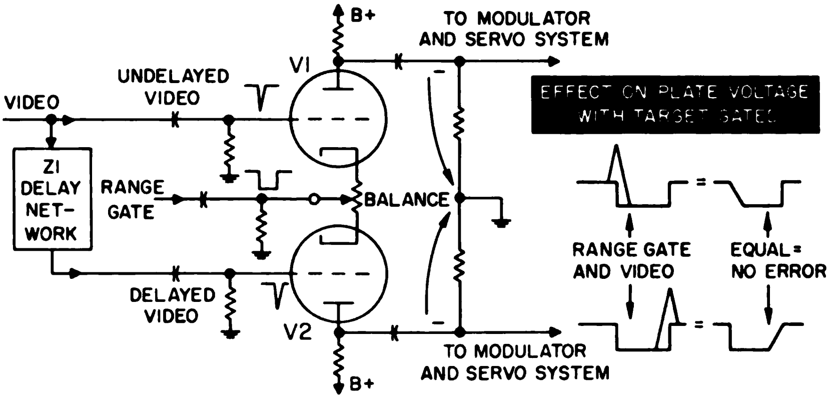
The circuit shown below represents a range error detector circuit in which only the range gate is available. Since the range gate is negative and is applied to both cathodes, each tube will pass the same amount of current. It can be seen that the average d-c potential of each plate will be the same, and no voltage difference will appear in the output of the error detector—indicating no range error.



307.—Range error detector circuit.

In your study of Coincidence Amplifiers, you saw how it was possible to establish a constant time delay between two signals. Another means of obtaining a delay is through the use of an "artificial" transmission line, terminated in its characteristic impedance. This principle was discussed in Volume V of NAVPERS 91886. Range error detector circuits use these "artificial" transmission lines to delay signals.

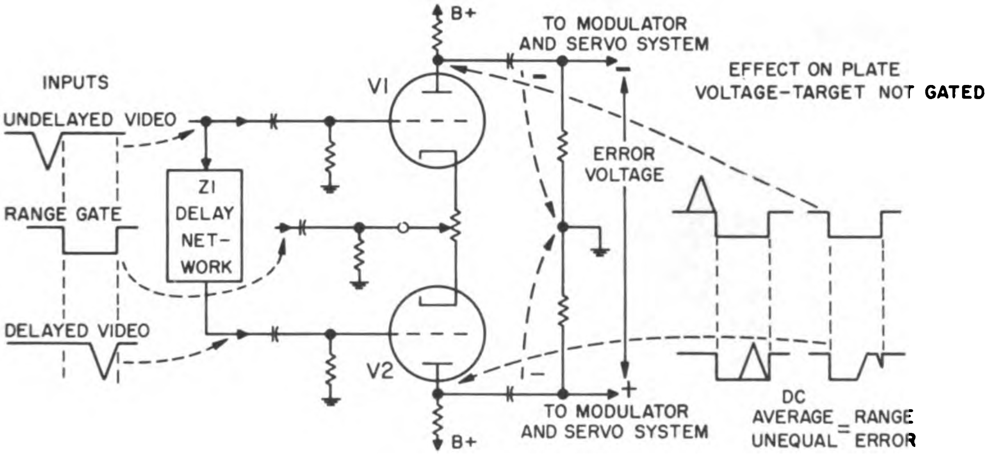
In the diagram below, video is applied to the grid of V1 and also to the input terminal of Z1. The video that appears at the output terminal is delayed by an amount equal to the width of the range gate. It is then applied to the grid of V2. If the delayed video occurs during the range gate for the same length of time as the undelayed video, the average d-c plate potential of V1 and V2 will be the same, and no error voltage is developed—the servo system will respond by remaining stationary.



308.—Range error detector circuit with delay net work (I).

Range Error (Continued)

Now, if the target (video) moves, there will be a change in the average plate potential of V1 and V2. Assume that the target is approaching the ship. Then, in the diagram, the video will move to the left. It is the purpose of the error detector to detect this movement and produce a voltage which will cause the range servo system to move the range delay potentiometer and the phase-shift capacitor so that the range gate will also move to the left to remove the error.


B+
TO MODULATOR AND SERVO SYSTEM
EFFECT ON PLATE VOLTAGE-TARGET NOT GATED
INPUTS
UNDELAYED VIDEO
V1
ERROR VOLTAGE
Z1 DELAY NET-WORK
RANGE GATE
DELAYED VIDEO
V2
TO MODULATOR AND SERVO SYSTEM
B+
DC AVERAGE UNEQUAL = RANGE ERROR
-
+

309.—Range error detector with delay network (II).

Notice that none or very little of the undelayed video occurs during the range gate. Thus, the effect of the gate is felt entirely in the plate circuit of V1. Since the delayed video occurs wholly during the range gate, it reduces the effect of the gate in the plate circuit of V2. This action produces an unbalance (difference) in the average d-c potential in the plate circuits of the two tubes. The resultant output is such that one side is negative with respect to the other. The amount of this difference represents the amount of error, while the polarity represents the direction of the error. In this case, the target moved to the left of the range gate (decreasing range) and produced the indicated polarity. If the video (target) had moved to the right (increasing range), the output polarity would have been reversed.

The output of the range error detector shown above is applied to a servo amplifier, then to a servo motor. The servo motor converts the error voltage to a mechanical rotation of a shaft. This shaft moves the phase-shift capacitor and the range delay potentiometer which change the time of occurrence of the range gate, so that it will move in the same direction as the video. When the two video signals are again centered about the gate, the error is reduced to zero and the servo system stops.

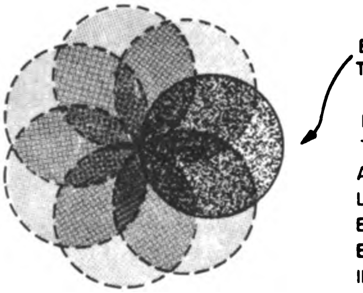
This is a continuing process in range error detectors when tracking moving targets. Actually, as long as the video (target) continues to move, the error detector circuits and servo system continue to operate to reduce the error to zero. One feature of all automatic tracking systems that you should remember is that they require an error to fulfill their function. The smaller the error required for error detector operation, the more efficient will be the automatic tracking of the system concerned.

ERROR DETECTING CIRCUITS

Train and Elevation Errors

The radar range (A) indicator presentation cannot be used by the director operators to determine accurately train and elevation errors. For accuracy in determining the train and elevation of a target, modern fire control radars use "B" and "E" presentations and employ conical scanning.

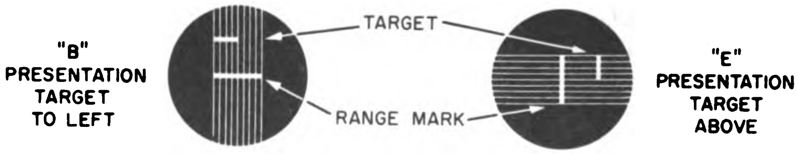
Conical scanning is the process by which the radar beam is moved in a circle. The rate of this circular motion is 30 cycles per second. A 30-cycle generator is driven by the same mechanism that provides the circular motion of the beam. Conical scanning and the sine-wave generator signal provide the means by which errors in train and elevation can be determined.


BEAM POSITION FOR ONE TRANSMITTER PULSE.

BEAM POSITIONS FOR TRANSMITTER PULSES ARE SHOWN BY DOTTED CIRCLES. LIGHT SHADED AREA INDICATES EFFECTIVE BEAM COVERAGE AND EXTENDS OUT FROM THE ANTENNA IN THE SHAPE OF A CONE.

310. —Conical scanning.

Synchronization of the position of the range sweep and the position of the radar beam is used in the "B" and "E" presentations to provide the director operators with a method by which train and elevation errors are determined. The outputs of the generator are referred to as the train and elevation reference voltages. The train operator uses the "B" (bearing) presentation to visually determine the error in train. The elevation operator uses the "E" (elevation) presentation to visually determine the error in elevation.

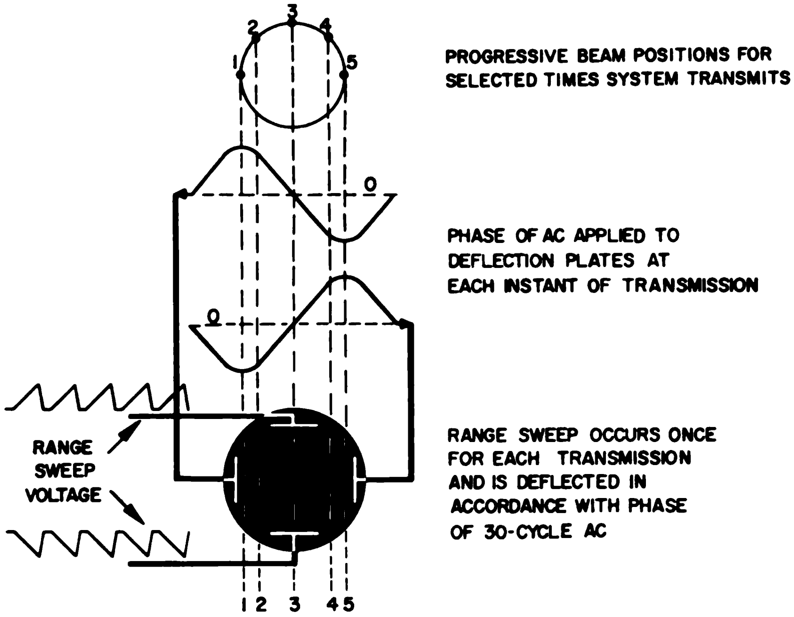


311. —"B" and "E" presentations.

Using the diagram on the opposite page, analyze the "B" sweep presentation without video. The radar beam position, the 30-cycle sine wave, and the indicator presentation are synchronized as indicated. When the radar beam is in its top position, the 30-cycle voltage on each horizontal deflection plate is zero. The range sweep developed will then appear in the center of the CR tube. When the radar beam is in its extreme right position, the 30-cycle voltage on the left deflection plate will be maximum negative and that on the right deflection plate will be maximum positive. The range sweep produced will then appear farthest to the right on the CR tube. When the radar beam is in the bottom position, the 30-cycle voltage on each horizontal deflection plate is again zero, and the range sweep will again appear in the center of the CR tube. With the radar beam in its

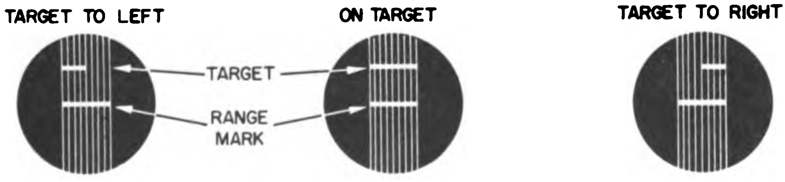
Train and Elevation Errors (Continued)

extreme left position, the 30-cycle voltage on the left deflection plate is maximum positive and that on the right deflection plate is maximum negative. The range sweep produced at that time will be farthest to the left on the CR tube.


1
2
3
4
5
PROGRESSIVE BEAM POSITIONS FOR SELECTED TIMES SYSTEM TRANSMITS
0
PHASE OF AC APPLIED TO DEFLECTION PLATES AT EACH INSTANT OF TRANSMISSION
0
RANGE SWEEP VOLTAGE
RANGE SWEEP OCCURS ONCE FOR EACH TRANSMISSION AND IS DEFLECTED IN ACCORDANCE WITH PHASE OF 30-CYCLE AC
1 2 3 4 5

312. —"B" sweep presentation without video.

With a target in the center of the radar beam coverage, the target echo will be of equal strength on each range sweep. The target video will extend across the "B" sweep as shown in the diagram below.



313. —"B" sweep presentation with video.

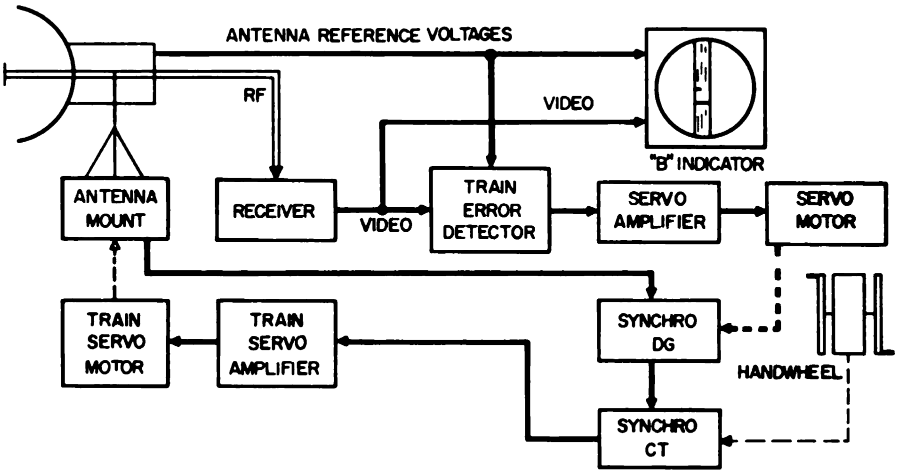
With a target in the left portion of the radar beam coverage, the target echo will be of greatest amplitude when the beam is to the left. The most video will appear on the sweeps that are presented at that time. The presentation will show the target to the left on the "B" sweep. If the target were in the right portion of the radar beam coverage, the video would appear on the right portion of the "B" sweep. The "B" indicator gives the train operator a presentation that he may use for determining train errors.

The "E" sweep presentation is synchronized in a similar manner and provides the elevation operator with a visual indication that he may use to determine elevation errors.

ERROR DETECTING CIRCUITS

Train and Elevation Error Detecting

In manual radar tracking in train and elevation, the director operators are the error detectors. The train operator observes the target video position on the "B" indicator to determine the train error. He then turns his train handwheel in the direction that the train servo system will eliminate the error. The elevation operator observes the "E" indicator to determine the elevation error. He then turns his elevation handwheel in the direction that the elevation servo system will eliminate the error. In tracking most radar targets, there will be errors in both train and elevation. Each operator will turn his handwheel in a direction to eliminate his error and both errors will be eliminated.

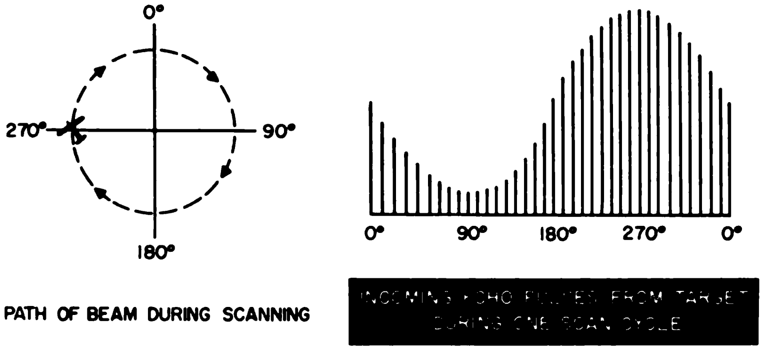


314.—Manual radar tracking in train.

The automatic error detecting circuits in train and elevation require an input signal that can be obtained from the video signals. When the antenna is pointing directly at the target, the amplitude of video signals received during one cycle of antenna scan will be equal. If the antenna is not pointing directly at the target, the amplitude of successive video signals will vary. The video envelope will be a 30-cycle (antenna scan rate) signal. The phase of this 30-cycle signal is established by the position of the target relative to the center of the beam coverage of the radar.

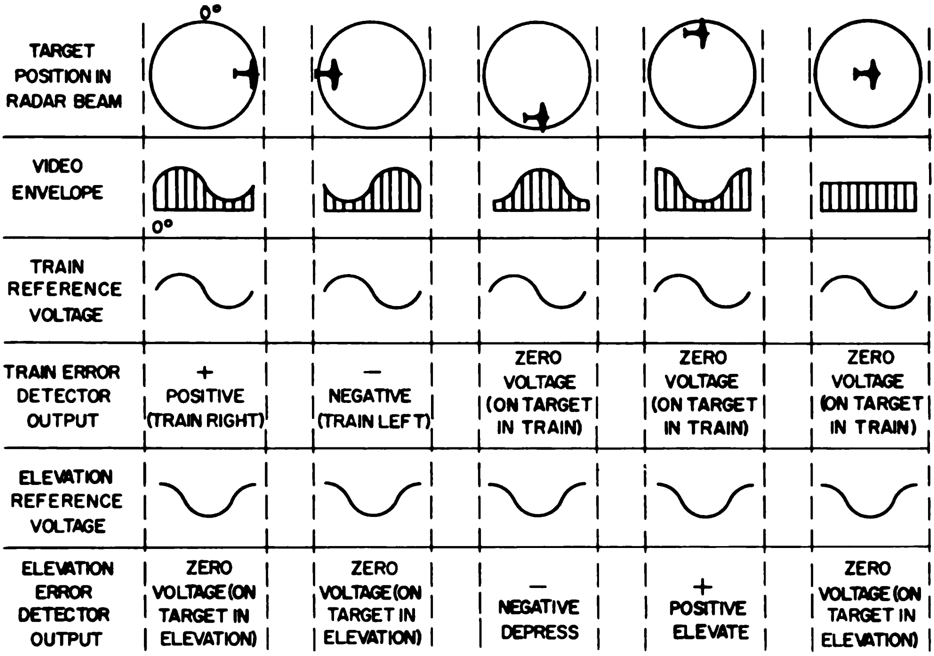
Let us assume that the target is in the left-hand portion of the beam coverage of the radar. The video returned from the target when the center of the beam is in its top position will be relatively small. As the center of the beam moves in its clockwise direction to the right, each successive video signal will become smaller. Minimum target video amplitude will be reached when the center of the beam has moved to its extreme right position. As the beam center moves to the left, successive video pulses from the target will increase in amplitude until maximum is reached with the beam center in its extreme left position. Further clockwise movement of the beam center moves the beam center away from the target and video signals will reduce in amplitude. Notice that the video envelope is a sine wave with maximum negative when the beam center is to the right and maximum positive when the beam center is to left.

Train and Elevation Error Detecting (Continued)


0°
270°
90°
180°
PATH OF BEAM DURING SCANNING
0°
90°
180°
270°
0°
INCOMING ECHO PULSES FROM TARGET
DURING ONE SCAN CYCLE

315. —Scan path and target echo pulses.

If the target had been to the right of the center of the coverage of the radar beam, the phase of the video envelope would have been inverted. With a target in any other portion of the beam coverage, the phase of the video envelope signal will be different. Comparison of the phase of this signal with the phase of the train and elevation reference voltages is the function of the train and elevation error detecting circuits.


0°
TARGET POSITION IN RADAR BEAM
VIDEO ENVELOPE
0°
TRAIN REFERENCE VOLTAGE
TRAIN ERROR DETECTOR OUTPUT
+ POSITIVE (TRAIN RIGHT)
− NEGATIVE (TRAIN LEFT)
ZERO VOLTAGE (ON TARGET IN TRAIN)
ZERO VOLTAGE (ON TARGET IN TRAIN)
ZERO VOLTAGE (ON TARGET IN TRAIN)
ELEVATION REFERENCE VOLTAGE
ELEVATION ERROR DETECTOR OUTPUT
ZERO VOLTAGE (ON TARGET IN ELEVATION)
ZERO VOLTAGE (ON TARGET IN ELEVATION)
− NEGATIVE DEPRESS
+ POSITIVE ELEVATE
ZERO VOLTAGE (ON TARGET IN ELEVATION)

316. —Changes in video envelope phase with different target positions.

The output of the train error detecting circuit (positive or negative) will be used in the train servo system to move the antenna to an "on target" position in train.

The output of the elevation error detecting circuit (positive or negative) will be used in the elevation servo system to move the antenna to an "on target" position in elevation.

ERROR DETECTING CIRCUITS

Review

1. A synchro servo loop is a basic error detecting system.
2. Tube circuits which compare the time of occurrence of two or more signals are used in range error detecting circuits.
3. Other tube circuits that compare the phase relationship of two signals are used in train and elevation error detector circuits.
4. Range error detectors determine if the range gate is at a shorter or longer range than the target.
5. Train error detectors determine if the antenna is to the right or left of the target.
6. Elevation error detectors determine if the antenna is above or below the target.
7. Error detector circuits make possible the automatic tracking features of fire control radar equipments.

Notes

TOPIC 15: THE MAGNETRON OSCILLATOR

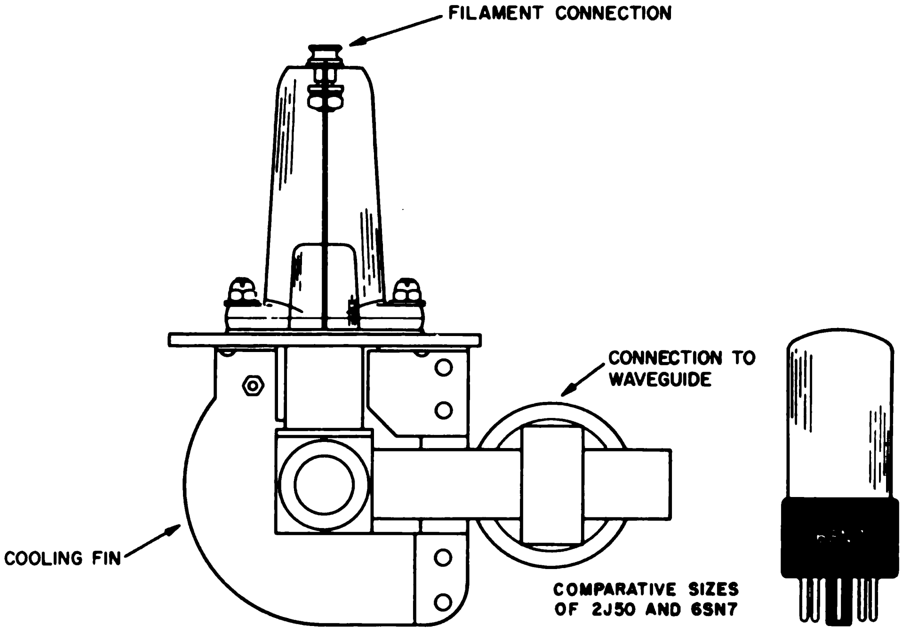
A High-Frequency Oscillator

All present day fire control radar transmitters use a magnetron oscillator to generate their RF energy. The magnetron is an RF oscillator that is turned on for a very short period of time, usually less than a microsecond, and is then turned off for comparatively long periods of time, usually several hundred microseconds. It is during the off time of the magnetron that the radar receiver is operating to receive RF energy that is reflected back to the antenna from objects in the path of the radar beam. To obtain sufficient reflected energy, it is necessary that the magnetron be capable of providing RF energy at high-power output.

The magnetron is a combination electronic and magnetic device that is capable of producing extremely high frequencies. It is the most practical means that has been devised to generate the high-frequency, high-power RF output with the short duration required by fire control radars.

The magnetron is a special type diode vacuum tube. It is constructed as a cylindrical diode; the plate surrounds the cathode. A magnet is mounted so that the magnetic field is applied in a direction parallel to the plate and cathode cylinders.

Due to the high-power output requirements of the magnetron, a large amount of heat is generated in the tube. To prevent damage from overheating, cooling fins have been added to the external structure of the tube. High-power magnetrons require additional forced air cooling.

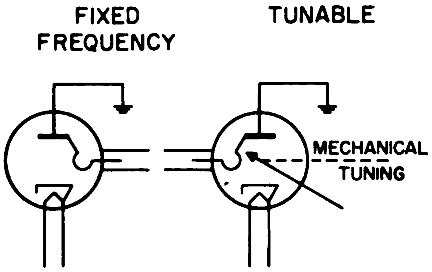


317.—Magnetron (2J50).

A High-Frequency Oscillator (Continued)

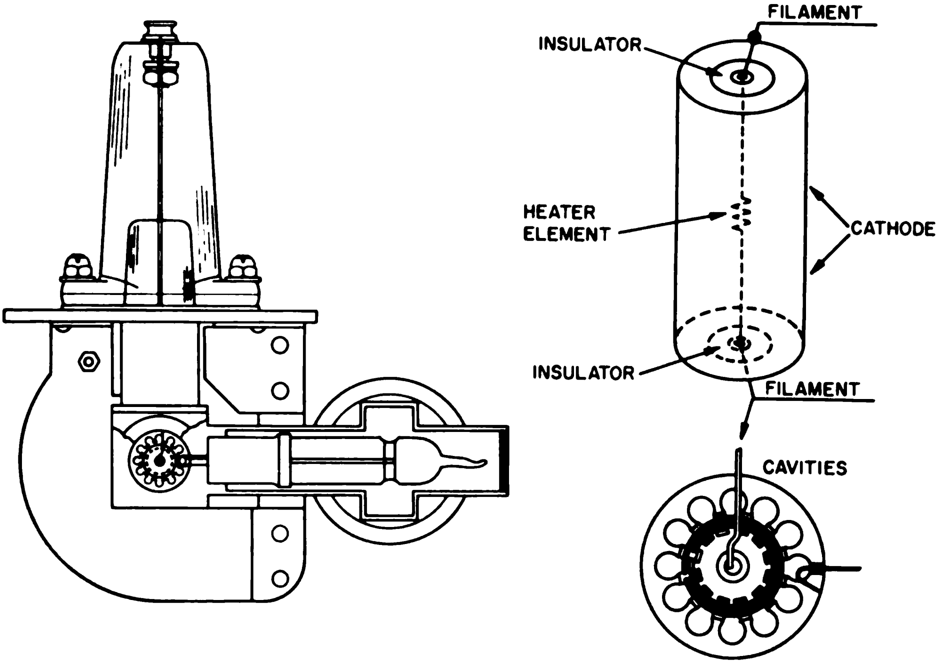
On schematic diagrams, only the electrical equivalent of a magnetron is shown and it looks very much like a diode except for the coupling loop.

Some magnetrons oscillate at a fixed frequency and others are tunable over a band of frequencies. Their schematic representations are shown at the right.



318. —Magnetron schematic symbols.

The physical appearance of the magnetron differs radically from that of the ordinary diode. The cathode is the small cylinder in the left center of the cutaway portion. To the cathode is connected one of the filament leads. The heating element is within the cathode and the other filament lead is connected to the opposite end of the heating element. Note that the filament leads provide support for the cathode.



319. —Magnetron configuration

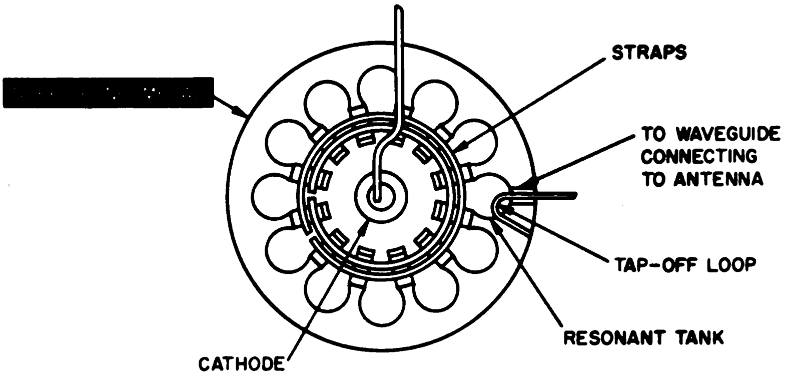
The plate of the magnetron is the metallic portion of the tube surrounding the cathode. On the inside perimeter of the plate are twelve resonant cavities. (Some magnetrons have less cavities and others have more.) Alternate segments of the plate are connected in parallel by the rings that can be seen on the inside edge of the plate surface. The coupling loop, shown over the cavity on the right, couples the RF power from the parallel-connected cavities to the waveguide.

A High-Frequency Oscillator (Continued)

In a diode, electrons normally flow directly from the cathode to the plate. In a magnetron, the magnet deflects the electrons from a direct path and causes them to move in an arc toward the plate.

You have noted the resonant cavities on the inside perimeter of the magnetron. These cavities produce RF oscillations which are reinforced by the electrons traveling toward them. This reinforcing action is the source of the high-power output of the magnetron. These cavities are called tank circuits since they resonate at a frequency dependent upon the size of the cavity. Since these cavities are quite small, high frequencies are developed.

In some types of magnetrons, the size of the cavities can be varied. This causes the tank circuits to resonate at a different frequency and therefore provides a means of varying the transmitted frequency of the radar. Variable frequency magnetrons will be encountered in most of the fire control radars that you will work with.



320. —Magnetron resonant cavities.

You know that at very high frequencies, currents tend to flow close to the surfaces of conductors. This means that additional metal can be placed around the outside of the loops, to give support to the device, without changing the properties of the tank circuits.

Since this gives the plate and tank circuits of the magnetron considerable bulk and area, it is easier to ground the plate rather than make it highly positive; therefore, to get the proper d-c plate-to-cathode potential required for oscillation, the cathode must be connected to a highly negative d-c source.

In normal operation, the magnetron is "pulsed" by placing a large negative voltage on the cathode for the duration of a fraction of a microsecond. This produces high-frequency oscillations in the magnetron for the same interval.

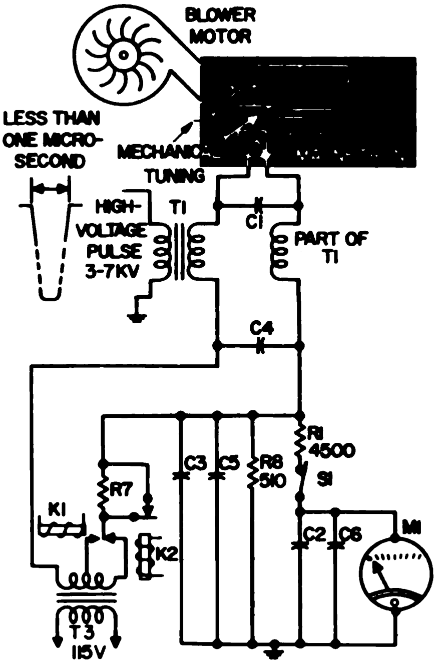
The RF energy generated in the tank circuits is then coupled from the magnetron by the simple means of tapping one of the tank circuits and coupling it to a wave guide which feeds the RF energy to the antenna.

A High-Frequency Oscillator (Continued)

Due to the large amount of metal in a magnetron, it would require a considerable time to bring the cathode to operating temperature. To decrease this time, the a-c voltage first applied to the filament is higher than the voltage that is necessary to maintain the cathode at the desired temperature. This increased filament voltage brings the cathode rapidly to operating temperature.

In the accompanying diagram, the full secondary voltage of T3 is applied to the filament until the operation of K1. This relay is a time delay relay and it is actuated several minutes after filament voltage is applied to the tube. K1 reduces the filament voltage by cutting down the number of turns used in the secondary winding of T3.

When the magnetron is oscillating, a large amount of current will flow through the tube. This produces considerable heat and makes it necessary to further reduce the filament voltage to prevent the cathode from exceeding its normal operating temperature. This reduction is accomplished by actuation of K2. With this relay actuated, R7, a voltage dropping resistor, is inserted into the filament voltage line. K2 is actuated when the radar equipment is placed in full "operate" condition.



321. —Filament voltage circuit.

The procedure of applying filament voltage in three stages is used with high-power magnetrons. In medium-power magnetrons, only one reduction in filament voltage is made and that occurs when the radar equipment is in operation (when the magnetron is oscillating).

The magnetron is pulsed by the negative high-voltage pulse applied to T1. This pulse is normally less than one microsecond duration and is stepped up in T1 from a few thousand volts to several times this amount.

Magnetron current that flows from cathode to plate during the high-voltage pulse is not measured, but average magnetron current may be measured. In the diagram, with S1 in the position shown, the meter will read the average magnetron current. Current flows from ground through R8, one side of the filament line to the cathode, then to the plate which is connected to ground. The meter and R1 are in parallel with R8.

The heat generated in a magnetron is conducted to the surface of the metal and is then dissipated into the surrounding air. Metal fins on the tube aid in carrying off the heat. In high-power magnetrons, a blower is used to force air to pass the surface of the tube to increase the dissipation of the heat.

THE MAGNETRON OSCILLATOR

Care of the Magnetron

The efficiency of the magnetron is dependent upon several factors. One of these is the strength of the magnet. To preserve the magnetic qualities, it is important that the magnet be protected from magnetic materials and sharp blows from screwdrivers and wrenches. Striking the magnet reduces its magnetic strength and lowers the power output of the magnetron.

When handling the magnetron, great care should be exercised. Jarring of the tube may disturb the physical arrangement of the tube elements. This will cause failure of the magnetron and possible damage to the circuits that supply the high-voltage pulse.

Trouble Indications

Fire control radar transmitters are equipped with metering circuits which usually provide the necessary indications by which the technician can detect a casualty to the magnetron.

These meters may be found in the plate, power supply, or triggering circuits of the magnetron.

The meter in the plate circuit indicates the magnetron current. If this is low, it usually indicates that the magnetron supply voltage or the trigger pulse is of insufficient amplitude. It may also indicate poor or low emission from the cathode.

The meter in the triggering circuit indicates how well the magnetron input circuits are matched to the triggering circuits, and also how well the magnetron output circuits are matched to the waveguide (transmission line). A low reading on this meter is desirable. A high reading usually indicates a poor impedance match either in the magnetron input or output circuits.

Meters are usually provided in the power supply circuits to indicate current and voltage outputs. High-voltage and low-current readings usually result from the loss of magnetron triggering signals.

Fluctuations in meter indications are usually produced by misfiring of the magnetron or arc-over in the magnetron circuits. This may be produced if the magnetron is being operated with a voltage higher than specified, or due to a faulty magnetron. This sometimes occurs when a new magnetron is first being used in the system and will require that a special magnetron-conditioning procedure be followed.

Proper interpretation of the meter readings available will provide a guide by which you may isolate the trouble to a particular component of the transmission system. Since high voltages are used in these circuits, almost all testing procedures will require that the system be shut down and the circuits checked with an ohmmeter.

THE MAGNETRON OSCILLATOR

Things to Remember about Magnetrons

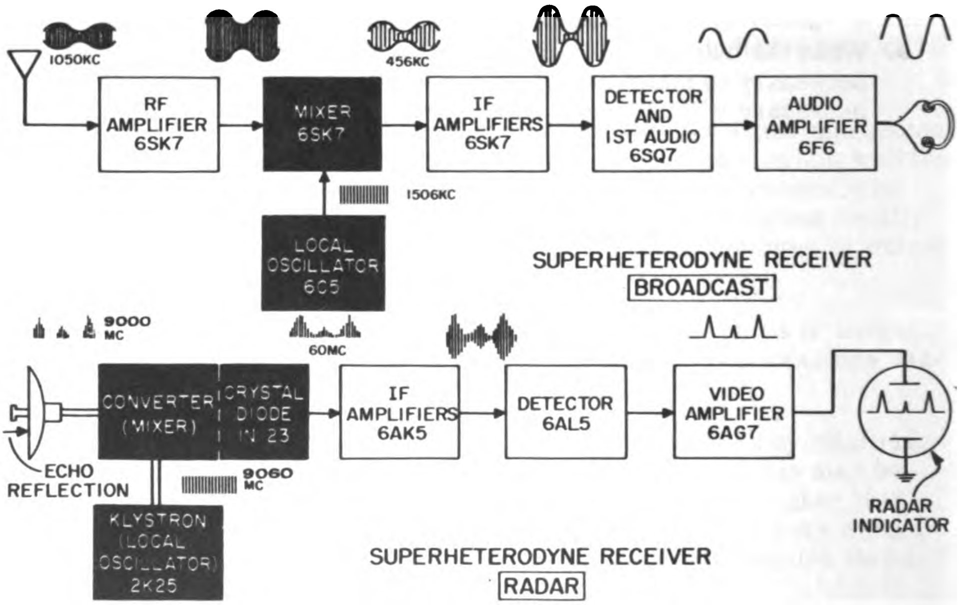
1. The magnetron is a combination electronic and magnetic device.
2. It produces the high frequencies required in radar transmission.
3. It can be pulse operated as required in radar equipments to give a short "on" time and a long "off" time.
4. It provides the high-power output required of radar transmitters.
5. The magnetron is an oscillator due to the effect of the magnetic field on the path of electrons flowing from cathode to plate and the resonant cavities in the tube structure.
6. The distance between the cathode and plate is important. Jolting or dropping a magnetron may change the operating characteristics so as to render the magnetron useless.
7. Do not strike the Alnico magnet with tools or other objects. Its magnetism can be greatly decreased by such action, which will affect the operation of the magnetron.
8. Use the nonmagnetic tools that are provided with the equipment when working on the magnetron.
9. When the magnetron is oscillating, a lower filament voltage is necessary to maintain the cathode at operating temperature than is necessary when it is not oscillating.

TOPIC 16: RADAR CONVERTERS AND KLYSTRONS

Superheterodyne Receivers

Radar receivers today universally employ the superheterodyne circuit to convert microwave signal frequencies to a frequency low enough to be amplified by standard RF amplifier circuits operating at high sensitivity and selectivity. However, because of the large conversion ratio from the input signal frequency to the intermediate frequency, and other special requirements of the radar receiver, the mixer and local oscillator stages employ circuits radically different from those you have been used to seeing in conventional superhet receivers.

In the superheterodyne receiver that you studied in Basic Electronics, you changed stations by rotating the rotor of the variable ganged tuning condenser. This changed the resonant frequency of the tuned circuit in the RF amplifier stage to the frequency of the desired station and changed the local oscillator frequency by the same amount to maintain the required intermediate frequency. The IF was amplified and detected. The detected audio frequency was amplified and used to drive a speaker, or you may have listened to it on a pair of earphones. If you were listening to a station on 1050 kc, the RF amplifier was tuned to 1050 kc and the local oscillator was tuned to 1506 kc, producing an IF of 456 kc. These frequencies are much lower than the frequencies used in radar, but the receiver principles are the same.



322.—Uses of superheterodyne receivers.

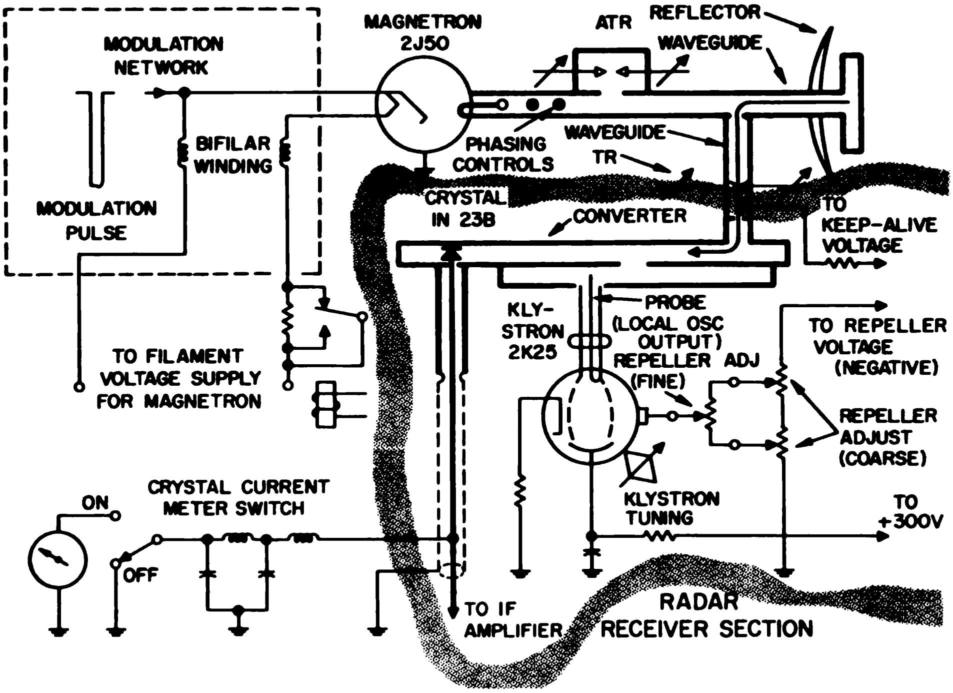
The block diagram of the superheterodyne receiver used in a radar is very similar to that used in a standard broadcast receiver. In the diagram, you will note that the frequency to be received is 9000 mc. No RF amplifier is used because of the problems involved in the amplification of so high a frequency. The received RF is coupled from the antenna to the converter where it is mixed with a frequency 60 mc higher to produce the desired IF of 60 mc. This frequency at 9060 mc is generated in the

Superheterodyne Receivers (Continued)

klystron, which is a special type local oscillator. The first detector in a radar receiver is a crystal, but in the broadcast receiver you used a vacuum tube. The 60 mc intermediate frequency is amplified in the IF stages and applied to the second detector, a 6AL5 duo-diode vacuum tube. The output of this detector will be voltage pulses with a duration equal to the echo pulse from the target and will reoccur at the PRF of the radar. If you listened to this signal with a pair of earphones, you would hear a signal at the frequency of the PRF. To make the output of this detector usable, it is amplified and presented on a CR tube.

In a broadcast receiver, the output intelligence is audio. In a radar, the output intelligence is video (presented on a radar indicator tube).

'The big differences between these two superheterodyne receivers are in the local oscillator and converter (mixer). You are familiar with these two parts of your superheterodyne receiver. In the schematic below are shown these two parts of a radar receiver.



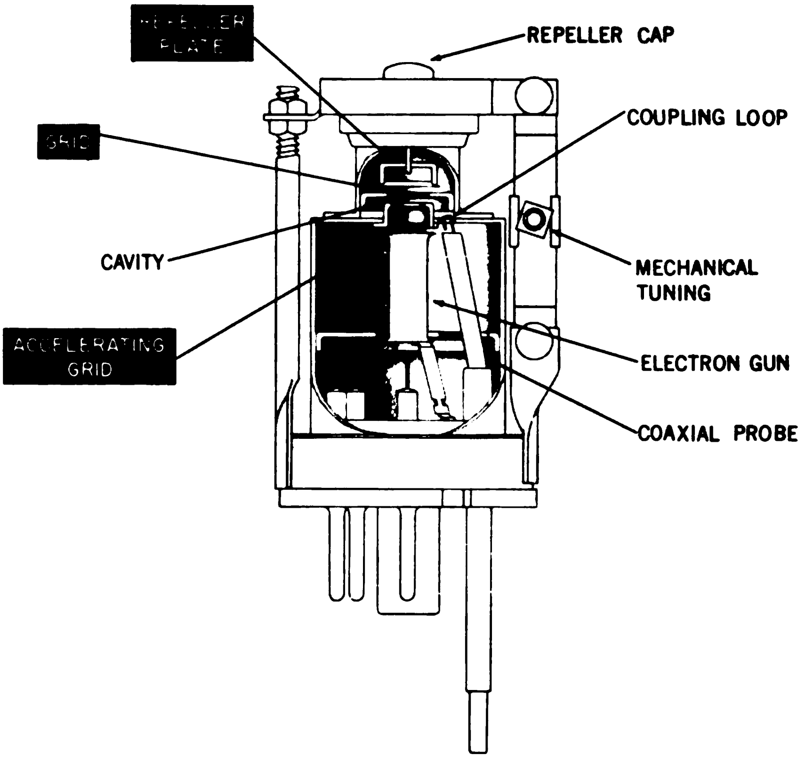
323. —Radar superheterodyne receiver.

In the diagram, the local oscillator is a type 2K25 klystron. This oscillator is tuned by adjusting the repeller voltage and adjusting the cavity grid spacing. Its output frequency is fed into the converter section of waveguide by means of a probe. The reflected RF energy is coupled to the same waveguide section. The 1N23B type crystal is used as the first detector. The output of the crystal is coupled through coaxial cable to the IF amplifier. The IF amplifier input is tuned to 60 mc, the difference frequency.

Klystrons

The klystron-type local oscillator does not use an ordinary tuned circuit as such; its tuned circuit is built into the tube structure and in physical appearance resembles a cavity enclosed by metal.

Ordinary coils and capacitors cannot be used in tuned circuits at radar frequencies because they would have to be too small to be practical. In addition, the high losses incurred in regular components at these high frequencies would result in an excessively low Q tank circuit. Another important factor to be considered is that leads of ordinary components would be an appreciable portion of a wavelength long. These problems are avoided by using a type of tuned circuit in the klystron that is completely enclosed, as is the case with a resonant cavity.



324.—2K25 klystron.

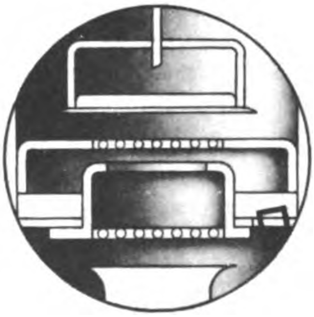
The picture of the 2K25 klystron shown above was made with a portion of the shell of the tube cut away so that internal components of the tube would be visible. The picture shows the tube slightly larger than actual size.

The two major factors that determine the frequency of oscillation of the klystron are the repeller (negative) voltage and the cavity grid spacing. The repeller voltage is adjusted in the external circuits. The cavity grid spacing is controlled by the mechanical tuning adjustment shown at the right of the tube.

Klystrons (Continued)

The reflex klystron which is used in modern fire control radar receivers uses cavity resonators as tuned circuits. The electrons emitted by the cathode are formed into a thin beam and are given an initial velocity by the accelerating grid. They then pass through the grid structure of the cavity resonator. The cavity is in a state of oscillation produced by noise voltages or random fields. Thus, an electric field exists across the grid structure, the amplitude and direction of which, at any instant, depends upon the amplitude and direction of the RF voltage existing in the cavity at this same instant. This electric field, therefore, causes the deceleration of some electrons and the acceleration of others, depending upon the amplitude and direction of the electric field.

Beyond the grid structure, the slow electrons are overtaken by the fast ones, so that bunches of electrons are formed. These electron bunches are repelled by the negative potential of the repeller plate and so travel back toward the grid structure. If the repeller voltage is adjusted so that the electron bunches arrive at the grid structure just when the electric field is in such a direction as to decelerate them, they will slow down, and their resulting loss of energy reinforces the RF oscillations within the cavity resonator. Thus, the tube produces an amplification of power and oscillations are maintained.



325.—Reflex cavity resonator.

Because the klystron operating frequency can be varied as much as 1 percent by changing the repeller voltage, the klystron lends itself to automatic frequency control by means of electronic tuning. Automatic change of repeller voltage proportional to the IF drift may be used to compensate for the IF change.

The klystron frequency can also be tuned mechanically by flexing the tube envelope to vary the grid spacing, thus varying the capacity of the gap and the resonant frequency of the cavity.

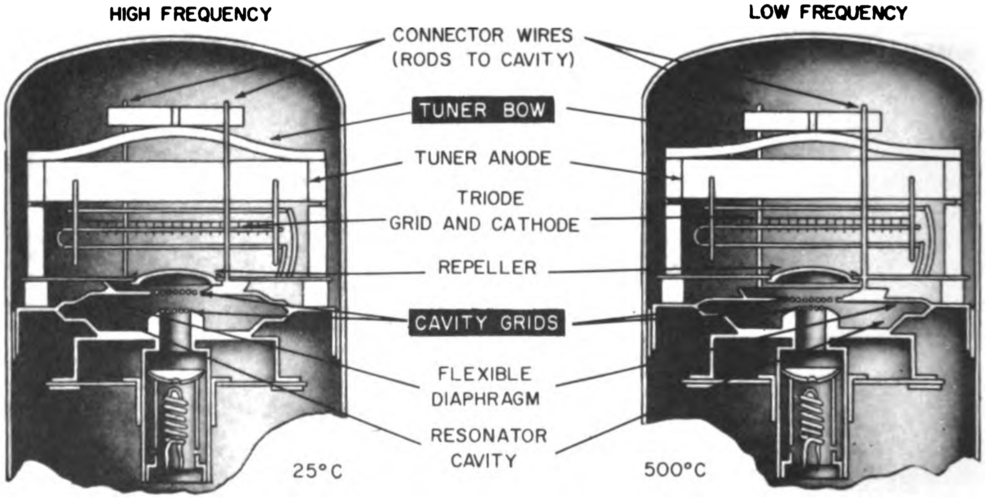
In a fire control radar transmitting at 9000 mc, the cavity and the repeller voltage are adjusted so that the output frequency of the klystron is 9060 mc, provided that the IF of the equipment is 60 mc. If the transmitter is changed to some new frequency, 8800 mc as an example, then it is necessary to readjust the cavity grid spacing and repeller voltage to maintain a difference frequency of 60 mc. To accomplish this, it is necessary to retune the klystron (local oscillator). This is done by adjusting the cavity grid spacing and the repeller voltage. In this example, the klystron would be set to 8860 mc, which once again produces a difference frequency of 60 mc.

Klystrons (Continued)

Another klystron that is used as the local oscillator in some radar receivers is the 2K45. Its principle of operation is very similar to that of the 2K25. The major difference between these two types is in the method by which the cavity grid spacing is changed. Tuning of the cavity in the 2K25 was accomplished by an external mechanical adjustment. In the 2K45, the mechanical adjustment of the cavity grid spacing is controlled thermally.

The 2K45 is actually two tubes in one shell. It contains a reflex klystron and a thermal tuning triode.

The thermal tuning triode controls the spacing of the cavity grids. By controlling the grid potential, as in a normal triode, plate current can be controlled. The amount of current flowing will determine the heat generated in the plate structure. Note the positions of the tuner bow in the two pictures below. Also, note the relative spacing of the cavity grids in the two pictures.



326. —2K45 klystron.

In the picture on the left, the voltage on the control grid of the triode is below cut-off. No current is flowing in the tube; no heat is being generated in the tuning anode. The tuner bow is bent upward, and the connector wires have raised the flexible diaphragm which forms the upper portion of the cavity. The spacing between the cavity grids is at maximum; the output frequency of the klystron is at maximum.

In the picture on the right, the voltage on the control grid of the triode is considerably above cut-off. Current flowing in the triode section has generated heat in the tuning anode. The metal in the tuning anode has expanded more than the metal in the tuner bow and has resulted in the tuner bow being bent downward toward the tuning anode. The downward motion of the tuner bow was transferred through the connector wires to the flexible diaphragm. The cavity grid spacing is at minimum; the klystron is at its lowest frequency.

Klystrons (Continued)

The thermal tuning triode feature of the 2K45 provides a means of automatic frequency control (AFC) of the local oscillator. It makes possible a wide change in frequency to search for the desired frequency. By applying the output of a multivibrator to the control grid of the triode, current in the tube may be turned on by the positive portion of the square wave and turned off by the negative portion of the square wave. The negative portion of the square wave cuts off tube current and holds the triode cut off for the duration of the negative portion. During this time, the tuning anode cools and the frequency of the klystron increases. The positive portion of the square wave turns on tube current and the heat generated in the tuner anode causes the frequency of the klystron to decrease. If the duration of the positive and negative portions of the square wave are long enough, the frequency of the klystron will reach both its upper and its lower limits.

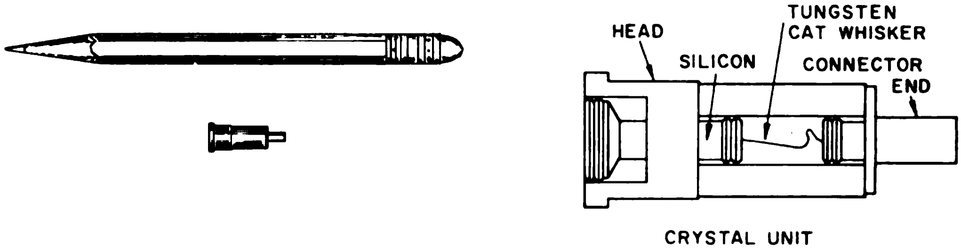
The alternate heating and cooling of the tuner anode results in the output frequency of the klystron sweeping upward and downward across its frequency range. If at the desired local oscillator frequency the repeller voltage is correct, the klystron signal coupled into the radar converter will mix with the magnetron frequency to produce the required intermediate frequency. The output of the radar converter is applied to IF amplifiers in the AFC unit. The IF signal is amplified (if it falls within the band pass of the IF amplifier circuits) by the IF amplifiers and is applied to an AFC discriminator, a frequency error detecting circuit. The output of the discriminator is used to trigger the multivibrator so as to control the time of the heating and cooling cycles of the thermal tuning triode. With AFC of the local oscillator output, the local oscillator is made to sweep in a narrow range about the desired frequency.

By adjusting the potential of the control grid of the thermal tuning triode between the limits of cut-off and some positive voltage, the output frequency of the klystron can be adjusted between its limits. This provides a much wider adjustment of frequency than by adjustment of the repeller voltage. However, changing the cavity grid spacing alone will not permit oscillations at the desired point within the frequency range. The repeller voltage must be changed at the same time as the cavity grid spacing if large changes in output frequency are desired.

Metering circuits are employed in fire control radar equipments to provide a means of localizing casualties in the receiver. No current means the loss of target echoes. No current may be due to a defective local oscillator or a defective crystal. It indicates that the klystron may not be oscillating. Lack of an output from the klystron may be due to improper tuning or a defective tube. If it is suspected that the klystron tube is bad, secure power to the equipment before attempting to replace the tube. There are 300 volts on the shell of the tube.

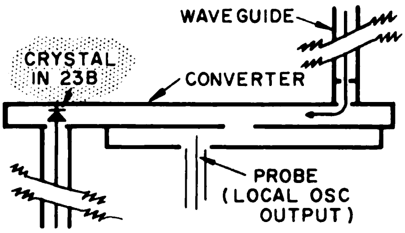
Radar RF Converter

The crystal used in the converter assembly of a radar receiver has properties similar to a diode; namely, it conducts mostly in one direction. Its current-voltage characteristics are also similar to those of a diode, being curved in the low voltage region.



327. —Crystal unit of radar rf converter.

The crystal substance is composed of the element silicon, which is a semiconductor; that is, it conducts current much more readily in one direction than in the other. The silicon crystal is firmly mounted in one end of a cartridge container. From the other end, a fine tungsten wire is made to come in contact with the crystal surface. The characteristics of this contact are carefully adjusted at the factory so that the crystal will have the specified properties. A filler material is poured into the cartridge to give its contents rigidity and also to seal it hermetically. Despite this type of construction, the crystal is still shock-sensitive and must be carefully handled. It can also be easily damaged by RF fields, static discharges, and excessive current. The sensitivity of the crystal is also known to decrease over a period of time, because of changes in the character of the contact point between the tungsten wire and the crystal face. However, these disadvantages in the use of the crystal are more than offset by the great advantage of low-noise generation.



328. —Crystal location in radar rf converter.

The crystal cartridge fits into a holder which is usually a section of a waveguide. This section also permits the introduction of the local oscillator (klystron) frequency and the RF; and the removal of the resulting IF. This complete assembly is called a converter, and a typical radar converter is shown above. The crystal is placed across the voltage points of the waveguide in such a position that its impedance matches that of the waveguide, thus effecting maximum power transfer to the crystal. The local oscillator signal is fed into the converter by means of a coaxial probe that extends into the waveguide.

RADAR CONVERTERS AND KLYSTRONS

Review

You will encounter several types of radar converters and local oscillators in your work with fire control radar equipments. The basic principles of operation are the same and are very similar to those principles employed in the mixer section of the common superheterodyne receiver used in commercial radios.

Some of the important points to remember about the information in this topic are listed below.

1. First, compare the superheterodyne receiver that you have worked with to the radar receiver that you will work with as a fire control technician.

[illegible]	[illegible]	SUPERHETERODYNE RADAR
RF Amplifier	Vacuum tube	None used
First Detector	Vacuum tube	Crystal diode
Mixer (Converter)	Vacuum tube	Waveguide section
Local Oscillator	Vacuum tube	Reflex klystron
IF	456 kc	60 mc
Antenna	Wire loop	Reflector and Waveguide
Tuning	Manual	Manual or AFC
Gain Control	Manual and AVC	Manual or AGC
Intelligence	Audio	Video

2. The crystal diode used in the converter of a radar receiver has the advantage over a vacuum tube in that it generates less noise than a vacuum tube at radar frequencies.
3. Crystal diodes must be protected against damage from shock, static discharges, high RF fields, and excessive current.
4. The klystron produces high-frequency oscillations by use of a resonant cavity.
5. The cavity grid spacing and the repeller voltage both must be adjusted for optimum operation of the klystron.
6. In the 2K25 type klystron, the cavity grid spacing is tuned by an external mechanical adjustment.
7. In the 2K45 klystron, the cavity is controlled by a thermal tuning triode in the same tube envelope.
8. The repeller potential for a klystron is a negative voltage.
9. Automatic control of the frequency (AFC) of a klystron may be obtained over a limited frequency range by applying a corrective signal to the repeller voltage.
10. Automatic control of the frequency (AFC) of the thermal tuned klystron can be obtained over a wide frequency range by using the corrective signal to control the grid voltage of the thermal tuning triode.

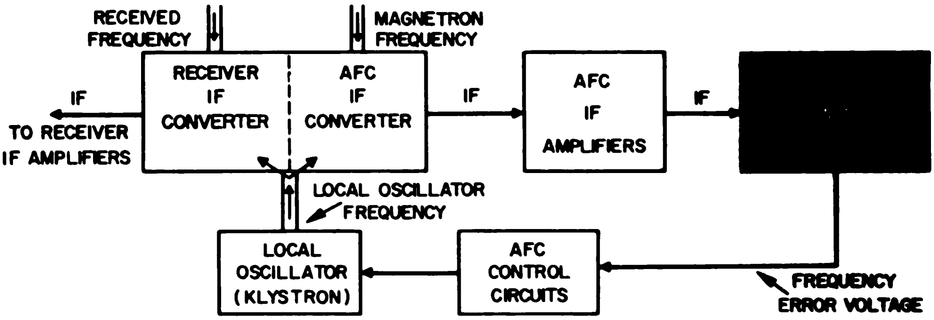
TOPIC 17: DISCRIMINATORS IN AFC CIRCUITS

General Purpose

Even though the design and construction of fire control radar equipments are very exacting, the frequency of the magnetron, or of the local oscillator, occasionally changes. These frequency changes cause considerable trouble at the radar receiver. A change in either the magnetron frequency or the local oscillator frequency will change the intermediate frequency being applied to the IF amplifiers. The output of the receiver is reduced, and weak target echoes may no longer be visible on the radar indicator. Any change in magnetron frequency, or local oscillator frequency, requires continual readjustment of receiver tuning or the employment of an automatic tuning device. Constant frequency checking by the operator is time consuming and prevents him from accomplishing his other duties when the radar is in operation. Therefore, most fire control radars employ automatic frequency control (AFC) circuits in which changes in frequency are detected by a discriminator circuit.

The purpose of the discriminator in AFC circuits is to develop a d-c voltage output with a polarity that is determined by the direction of the frequency shift from the intermediate frequency, and that has an amplitude that is determined by the amount of the frequency variation from the intermediate frequency. The discriminator in AFC circuits is a frequency error detecting circuit. Like other error detecting circuits, its output may be zero, some positive voltage, or some negative voltage. No output is an indication of no error. A positive voltage output is an indication of an error in one direction. A negative voltage output is an indication of an error in the opposite direction.

The output of the discriminator is applied as a correction voltage to the automatic frequency control circuits. These circuits in turn develop a correction voltage that is applied to the klystron so as to change the local oscillator frequency by an amount necessary to produce the desired intermediate frequency.



329. —Discriminator in AFC circuit.

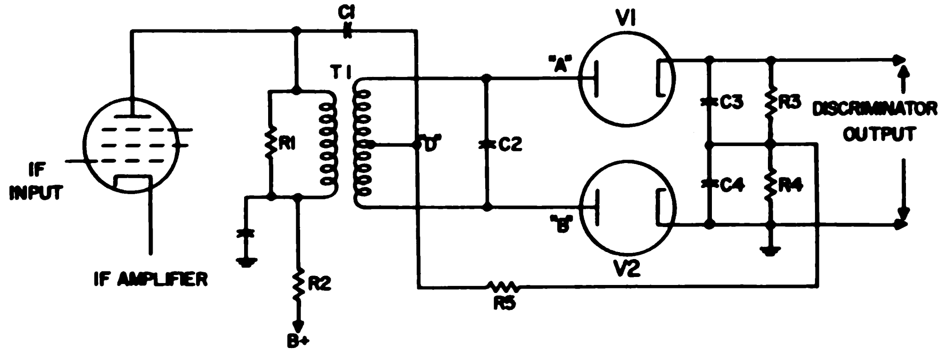
From the block diagram, you can see that the radar converter has two sections, an AFC section and a receiver section. The local oscillator frequency is fed into both sections. In the AFC section, the local oscillator frequency is mixed with the magnetron frequency to produce the difference frequency, the intermediate frequency. By maintaining the local oscillator frequency at the correct frequency, it is assured that the IF signal will be at the designed intermediate frequency of the receiver.

DISCRIMINATORS IN AFC CIRCUITS

Basic Discriminator Circuit

The discriminator circuit develops an output voltage that is used to maintain the local oscillator at the correct frequency. The main section of the discriminator is a resonant circuit. This circuit will cause a d-c voltage to be produced in the output of the discriminator that will have a polarity that is determined by the frequency of the IF signal input. When the IF is at resonance, designed IF, there will be no d-c output from the discriminator and no reason to change the local oscillator frequency. When the IF increases, one polarity of output voltage will be developed by the discriminator, and when the IF decreases, the polarity of the output voltage will be reversed. The positive or negative d-c output voltage is used to maintain the local oscillator at the correct frequency. The amplitude of the output voltage is determined by the amount the IF increases or decreases from resonance.

The discriminator circuit consists of four sections. One section is composed of R3 and R4, across which the output d-c voltage is developed. The second section is composed of diodes V1 and V2. The current flow through the diodes determines the voltage across R3 and R4. The third, and main section, is composed of T1 and C2, which are frequency sensitive. This section is designed for the intermediate frequency. The fourth section is an amplifier used to amplify the IF output of the converter (mixer). R1 is shunted across the primary to broaden the band pass of the circuit.



330. —Basic discriminator circuit.

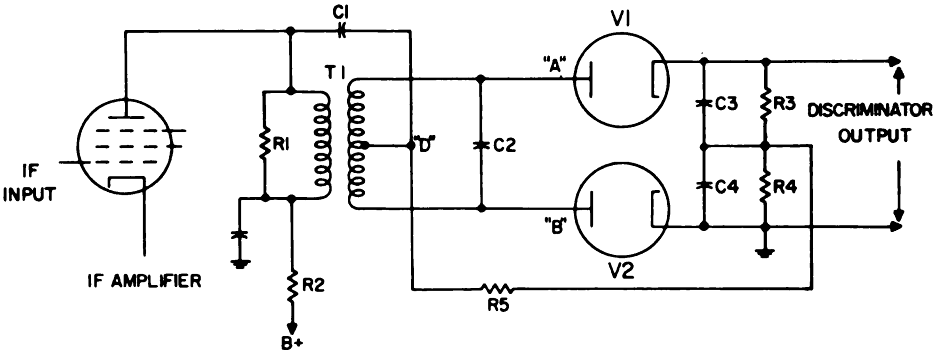
Let us see how a d-c voltage output can be developed. First, consider the current flowing through R3. Starting at the cathode of V1, trace through the tube to point "A," through the top half of the secondary of T1 to point "D," through R5 to the junction of R3 and R4, then through R3 to the cathode of V1. The amount of current flowing through V1 will determine the voltage drop across R3. Now, consider the current through R4. Starting at the cathode of V2, trace through the tube to point "B," through the lower end of T1 to point "D," through R5 to the junction of R3 and R4, then through R4 to the cathode of V2. You can see that if one diode passes more current than the other that a net d-c voltage will be developed in the output of the discriminator.

DISCRIMINATORS IN AFC CIRCUITS

Introduction to Circuit Operation

An error in the intermediate frequency will result in one of the diodes passing more current than the other. If there is no error, the current through the diodes will be the same, and the net d-c output voltage will be zero.

The voltage induced into the secondary will be small compared to the voltage developed across the inductance and capacitance by the circulating tank current. The voltage developed across the inductance, by the tank current, will provide the potentials that will cause V1 and V2 to conduct. Starting at point "A," trace through the top half of the secondary to point "D." The potential appearing across this part of the winding will appear between the plate and the cathode of V1. Next, starting at point "B," trace through the lower half of the secondary winding to point "D." The potential appearing across the lower half will be the plate-to-cathode potential of V2. You will note that point "D" is common to both diode circuits.



331. —Basic discriminator circuit.

The plates of V1 and V2 are at opposite ends of transformer T1. This means that the voltage on V1 will be 180 degrees out of phase with the voltage on V2. One tube will conduct while the other tube is not conducting. When the voltage in the secondary reverses polarity, the first tube will not conduct and the second tube will conduct for that half cycle.

In the discriminator circuit, the primary voltage of T1 is coupled through capacitor C1 to the secondary at point "D." This voltage appears equally on both diode plates. Now we can see that there are two voltages at points "A" and "B": the primary voltage and the voltage developed by the tank current. It is the phase relationship of these two voltages on the diode plates that is the key to discriminator circuit operation.

The two voltages combine vectorially to produce a resultant voltage that causes current to flow in the diodes. If the resultant plate voltages of the diodes are equal, the voltage drops across R3 and R4 will be equal and the net output voltage will be zero. If the resultant plate voltages are not equal, the voltage drops across R3 and R4 will not be equal and a net output voltage will be developed.

Introduction to Circuit Operation (Continued)

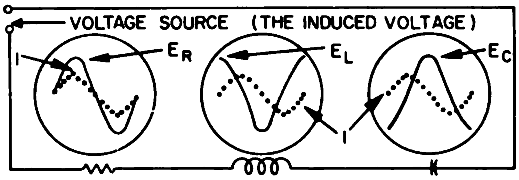
For comparison of the phase relationships of two voltages, it is necessary to establish a reference voltage. The primary voltage will be used as the reference. This voltage was chosen since it encounters no phase shift. The voltage across the secondary winding of T1 has a different phase relationship to the reference when the IF is at resonance, when the IF is above resonance, or when the IF is below resonance. When the IF is correct, the two voltages on the plate of V1 have a phase relationship that is as near to in-phase as the phase relationships of the two voltages on the plate of V2. At this time, the resultant voltages on the plates of the diodes are equal. The two tubes will pass the same amount of current, resulting in equal voltage drops across R3 and R4, and the net output voltage of the discriminator will be zero.

When the intermediate frequency is not correct, the two voltages at one end of the secondary will be closer to an in-phase relationship than the two voltages at the opposite end of the secondary. The resultant voltages will be unequal and there will be an output from the discriminator. The resultant voltages will be analyzed in each of three conditions: with the IF input to the discriminator at the correct frequency; with the IF above the resonant frequency; and with the IF below the resonant frequency.

The voltage induced in the secondary winding of T1 will be in phase, or 180 degrees out of phase, with the voltage in the primary. In the explanation of circuit operation, we will consider that the secondary is wound so that the voltage induced in it is 180 degrees out of phase with the primary voltage.

Before analyzing the resultant voltages on the diodes, let us review some of the basic information on resonant circuits that you studied in your course in Basic Electricity.

AT RESONANCE $X_L = X_C$, $E_L = E_C$, CURRENT IS MAXIMUM AND $Z = R$. E_R IS IN PHASE WITH THE CURRENT, E_L LEADS THE CURRENT BY 90 DEGREES AND E_C LAGS THE CURRENT BY 90 DEGREES.

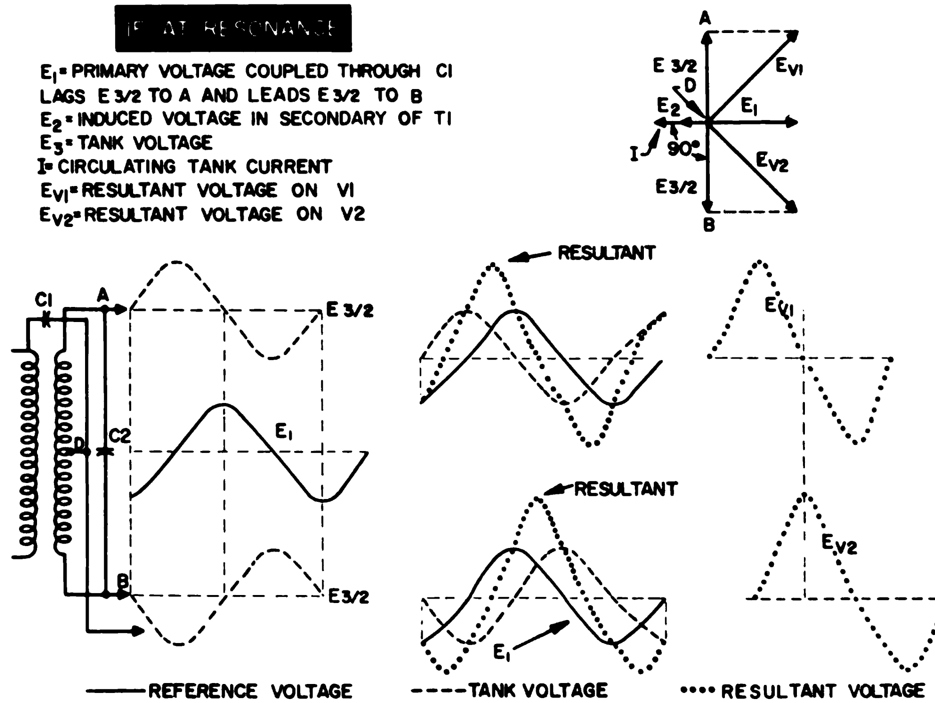


332.—Series resonant circuit voltages.

The voltage induced into the secondary will produce a circulating current in the tank circuit that will be in phase with the induced voltage at resonance, will lag the induced voltage at a frequency above the resonant frequency, and will lead the induced voltage at a frequency below the resonant frequency. The circulating tank current will be in phase with the induced voltage at resonance because the tank appears as a resistance. At a frequency above the resonant frequency, the circulating tank current will encounter more inductive reactance than capacitive reactance. At this frequency, the tank will appear as an inductance to the circulating tank current, causing it to lag the induced voltage. At a frequency below the resonant frequency, the circulating tank current will encounter more capacitive reactance than inductive reactance. At this frequency, the tank will appear as a capacitance to the circulating tank current, causing it to lead the induced voltage.

Discriminator Operation—IF At Resonance

With the IF at the resonant frequency of the tank circuit, let us analyze the two voltages at the plate of each of the diodes and establish the resultant voltage at the plate of each tube. Consider first the primary voltage coupled to the secondary through C1. This is the reference voltage and will be represented as E_1 on the vector diagram. It is drawn to the right from point D. The induced voltage, represented as E_2, will be 180 degrees out of phase with E_1. It is drawn to the left from point D. The circulating tank current will be in phase with the induced voltage and will develop a voltage across the secondary that will lead this current by 90 degrees. The voltage across the secondary is represented as E_3; it is the voltage from A to B in the schematic. Since one-half of this voltage is applied to V1 and the other half to V2, and the voltages at opposite ends of the transformer are 180 degrees out of phase, E_3 is 90 degrees out of phase with E_1 and E_2. The two voltages at one end of the secondary will be separated by 90 degrees; the two voltages at the opposite end will also be separated by 90 degrees. At one end of the secondary, the tank voltage will lead the primary voltage by 90 degrees, and at the other end, the tank voltage will lag the primary voltage by 90 degrees. The resultant voltages at each end of the secondary will be equal. The vector E_{v1} is the resultant voltage on V1; the vector E_{v2} is the resultant voltage on V2.


IF AT RESONANCE
E1 = PRIMARY VOLTAGE COUPLED THROUGH C1
LAGS E3/2 TO A AND LEADS E3/2 TO B
E2 = INDUCED VOLTAGE IN SECONDARY OF T1
E3 = TANK VOLTAGE
I = CIRCULATING TANK CURRENT
EV1 = RESULTANT VOLTAGE ON V1
EV2 = RESULTANT VOLTAGE ON V2
A
E3/2
D
E2
E1
EV1
I
90°
EV2
E3/2
B
C1
A
E3/2
C2
D
E1
B
E3/2
RESULTANT
EV1
RESULTANT
E1
EV2
——— REFERENCE VOLTAGE
- - - - TANK VOLTAGE
•••• RESULTANT VOLTAGE

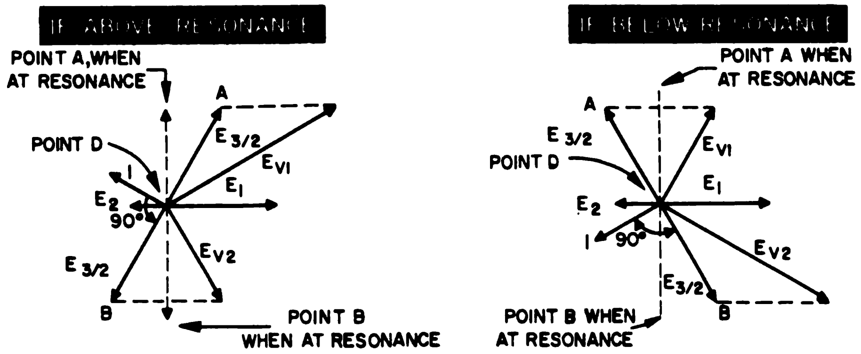
333.—Discriminator voltages at resonance.

At resonance, the diodes will have equal potentials on their plates. Both tubes will pass the same amount of current, resulting in a zero d-c output from the discriminator. No signal will be applied to the control circuits as no change in local oscillator frequency will be necessary.

Discriminator Operation—IF Off Resonance

Let us see what the potential on the plate of each diode is when the IF increases so that the input signal is above the resonant frequency of the tank circuit. E_1 remains the reference voltage, but the phase relationship between it and E_3 has changed. To the above-resonance frequency, the tank circuit appears as an inductance, since the inductive reactance of the secondary winding has increased and the capacitive reactance of C2 has decreased because of the higher frequency. Now the circulating current in the tank circuit is not in phase with the induced voltage. The circulating current, I, lags the induced voltage, E_2, by an angular amount determined by the frequency shift. The voltage E_3 across the inductance leads the circulating current by 90 degrees. The voltage across the secondary lags the voltage that was present when the IF was at the resonant frequency of the tank circuit. We now find that the phase relationship of E_1 and $E_3/2$ at point A is $E_{3/2}$ leading E_1 by less than 90 degrees. At point B, $E_{3/2}$ will lag E_1 by more than 90 degrees. Since the two voltages at A are closer to an in-phase relationship than the two voltages at B, the resultant voltage at A will exceed the resultant voltage at B. The vector E_{V1} is the resultant voltage on V1; the vector E_{V2} is the resultant voltage on V2. V1 will pass more current than V2. The voltage drop across R3 will exceed the voltage drop across R4; the net output voltage from the discriminator will be positive.

When the IF is above the resonant frequency of the tank circuit, the output of the basic discriminator circuit will be positive. This positive voltage will be used in the AFC control circuits to change the local oscillator frequency so that the correct IF is produced again.


IF ABOVE RESONANCE
POINT A,WHEN AT RESONANCE
A
POINT D
I
E3/2
EV1
E1
E2
90°
E3/2
EV2
B
POINT B WHEN AT RESONANCE
IF BELOW RESONANCE
POINT A WHEN AT RESONANCE
A
E3/2
POINT D
EV1
E1
E2
I
90°
EV2
E3/2
POINT B WHEN AT RESONANCE
B

334.—Discriminator voltages above and below resonance.

When the IF is below the resonant frequency, the tank circuit will be capacitive. The current, I, in the tank will lead the voltage induced in the secondary by an angular amount dependent upon the frequency shift. E_3 will lead this current by 90 degrees. $E_3/2$ and E_1 at point B are now closer to an in-phase relationship than $E_{3/2}$ and E_1 at point A. The resultant voltage on V2 will be greater than the resultant voltage on V1, and the output of the discriminator will be negative.

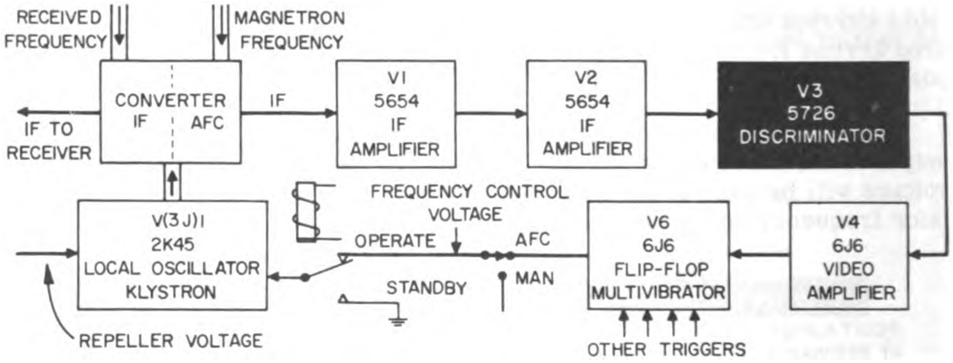
When the IF is below the resonant frequency of the tank circuit, the output of the basic discriminator will be negative. This negative voltage will be used in the AFC circuits to change the local oscillator frequency so that the correct IF is produced again.

DISCRIMINATORS IN AFC CIRCUITS

Application

One discriminator circuit application to fire control radar equipments will be given. This circuit is used in several radar equipments. You will notice that the discriminator circuit in the schematic on the opposite page is very similar to the basic one that you have studied.

The block diagram shows how the discriminator output is used in the AFC loop. The output of the discriminator will be positive or negative pulses occurring at the PRF of the radar equipment. These pulses will be used to control the operation of a "flip-flop" multivibrator. The square-wave output of the multivibrator is applied to the grid of the thermal tuning triode in the 2K45 klystron. The alternate heating and cooling of the anode on the alternate positive and negative outputs of the multivibrator will result in changes in the cavity grid spacing. These changes will cause the output frequency of the klystron to change downward and upward within a narrow frequency range and will maintain the intermediate frequency effectively at the center frequency of the band pass of the receiver.

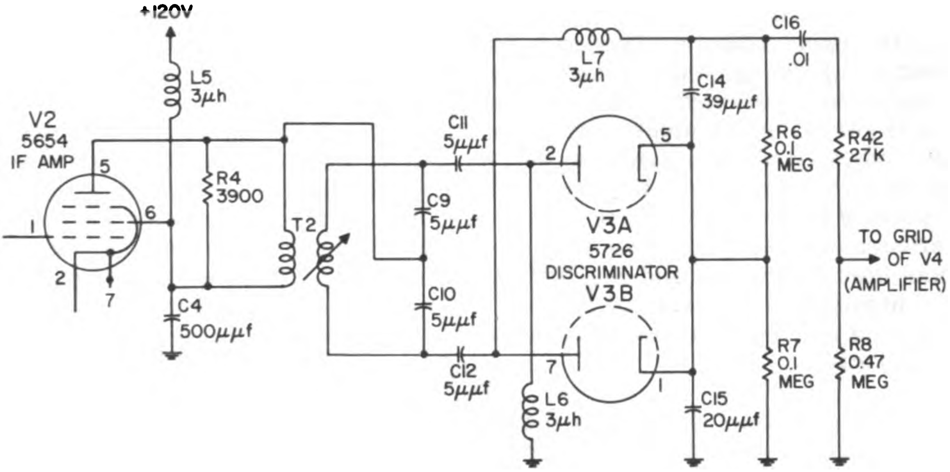


335.—Use of discriminator in Mark 25 Radar AFC loop.

The resultant voltages on plate pins 2 and 7 of V3 determine the output from the discriminator. The two voltages on plate pin 2 are the primary voltage and the tank voltage developed across C9, and the two voltages on plate pin 7 are the primary voltage and the tank voltage developed across C10. The voltage in the primary is coupled to the center of the tank circuit capacitance, C9 and C10, while in the basic circuit, the primary voltage was coupled to the center tap of the inductance. The two voltages on each plate combine vectorially, and the resultant voltages are the plate voltages for V3A and V3B. R6 and R7 are the load resistors for V3B and V3A.

When the IF is at the resonant frequency of the tank circuit, the resultant voltages on the plate of V3A and V3B will be equal and the net output voltage of the discriminator will be zero. When the IF is not at the resonant frequency, the resultant voltages on the two plates will be unequal and there will be an output from the discriminator. At a frequency below resonance, the output of the discriminator will be positive. At a frequency above resonance, the output will be negative. The reversal of the polarity of the output signal from that in the basic discriminator is due to the secondary of T2 being wound so that the voltage induced into the secondary is in phase with the primary voltage.

Application (Continued)



336.—Discriminator in Mark 25 Radar AFC loop.

In the discriminator used in fire control radar AFC circuits, the output voltages will not be continuous. The magnetron frequency will be available as one of the inputs to the radar converter during the time that the magnetron is oscillating. The magnetron frequency will be an input for very short periods of time, at the PRF of the radar. The local oscillator is oscillating continuously, but there will be an IF input to the discriminator only when both the magnetron and local oscillator are oscillating. The error voltage outputs will be positive or negative pulses occurring at the PRF of the radar.

Review

In this topic, you have studied the discriminator circuit and the part it plays in fire control radar equipment. Some of the highlights in this topic are listed below.

1. The discriminator circuit used for AFC is a frequency error detecting circuit.

2. It contains a tuned circuit that is resonant at the designed IF of the equipment.

3. Frequency variations from the designed IF are detected in the tuned circuit and produce a voltage whose polarity is determined by the direction of the intermediate frequency variation.

4. The magnitude of this output is determined by the amount of intermediate frequency variation.

5. AFC circuits provide a means by which the correct IF can be automatically maintained.

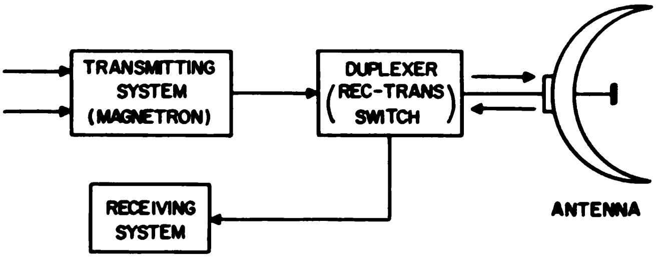
6. Maintaining the correct IF by controlling the local oscillator frequency means that the radar receiver is properly tuned and that reflected RF will be detected as video signals.

TOPIC 18: THE DUPLEXER

Receive-Transmit Switch

The radar receiver and the radar transmitter in a radar equipment use the same antenna. The magnetron oscillates for a fraction of a microsecond. This high-power, high-frequency energy that is generated is coupled to the antenna. This RF energy is beamed into space by the antenna reflector. Immediately after each transmission, the receiver must be connected to the antenna so that RF energy that is reflected by objects in the radar beam may be amplified and detected in order that video signals may be produced. It is impossible to use the same antenna for transmission and reception unless some fast-acting switch can be used. With both the transmitter and receiver connected to the antenna all of the time, the high-powered bursts of RF energy produced by the magnetron would burn out the crystals in the radar converter, and the receiver would be inoperative.

The switching device that makes it possible for the transmitter and the receiver to use the same antenna is called a duplexer. The antenna is normally connected to the receiver. This means that the duplexer must function to disconnect the receiver from the antenna and connect the transmitter to the antenna for the very short period of time that the magnetron is oscillating.



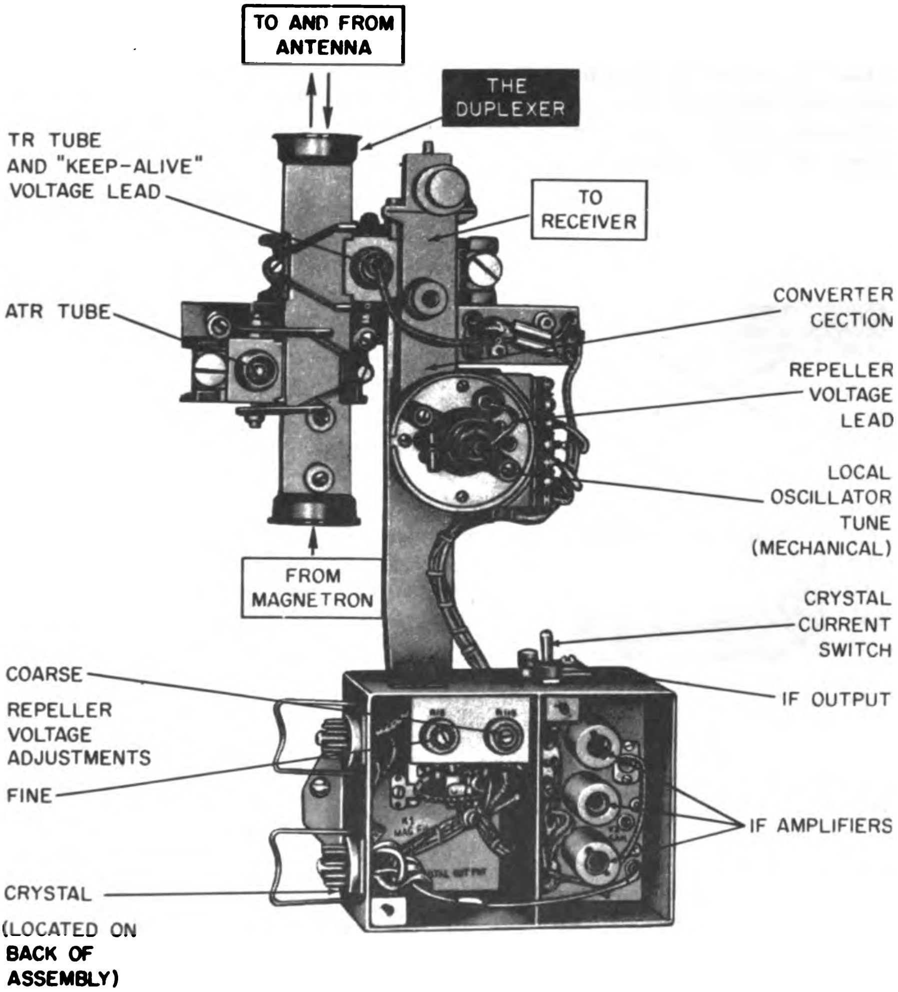
337.—The duplexer.

The switching action accomplished by the duplexer must be extremely fast. Let us assume that a radar equipment has a PRF (pulse repetition frequency) of 1000 pulses per second and that the duration of the magnetron oscillations is one-half microsecond. During each 1000-microsecond period, the transmitter will be operating for one-half microsecond. During the remaining time, the receiver will be connected to the antenna. The receiver must be disconnected from the antenna and the transmitter connected to the antenna in much less than one-half microsecond. After the radar transmission, the radar transmitter must be disconnected from the antenna and the receiver reconnected to it. Any delay in reconnecting the receiver to the antenna would result in the loss of echoes from close targets. Also, if the magnetron remained connected to the antenna, the reflected energy to the receiver would be less, since part of the reflected energy would go through the waveguide to the magnetron. This last problem would result in weaker targets not being detected.

THE DUPLEXER

A Radar RF Assembly

The illustration below shows an RF assembly of a fire control radar equipment. You are already familiar with some of the components of this assembly—the converter, local oscillator, and crystal. In this topic, you will be concerned with the duplexer. The main components in the duplexer are the waveguide sections and the TR and ATR tubes.



338. —Radar rf assembly .

The duplexer connects the high-power RF energy from the magnetron, when it is oscillating, to the antenna and prevents this energy from being connected to the receiver. At the end of the RF transmission, the antenna is connected to the receiver.

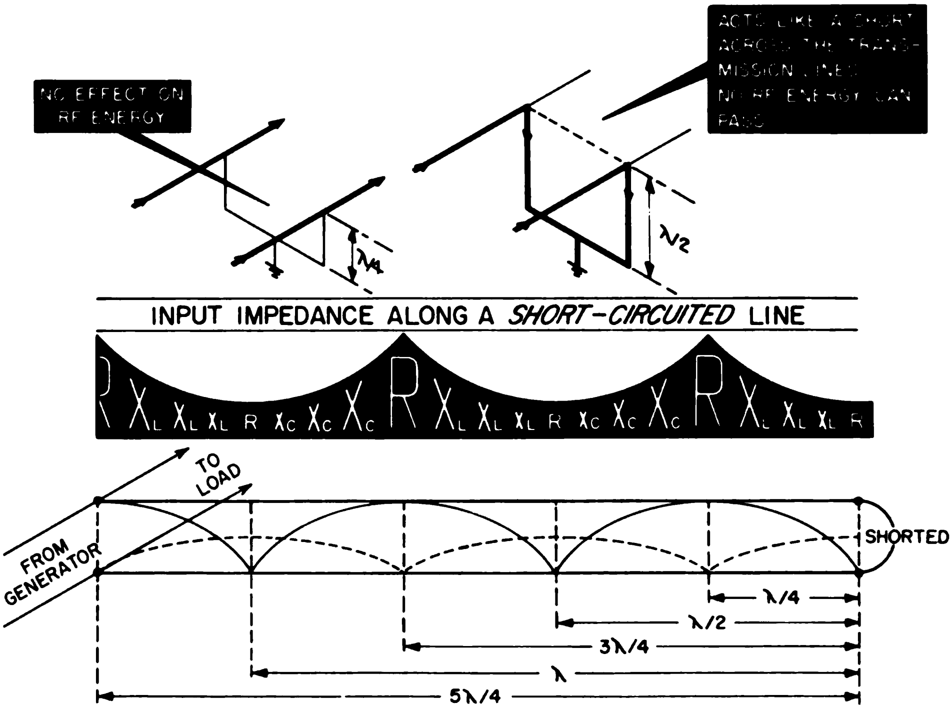
The radar duplexer is composed of sections of waveguide and gas-filled tubes. The waveguide sections are of critical lengths, and these tubes are located at points that are critical lengths along the waveguide sections.

Transmission Lines

In order to better understand the operation of duplexers, it is a good idea to review transmission lines.

When you studied transmitters in your Basic Electronics course, you learned about transmission lines. An important point you covered was the action of one-quarter wavelength and one-half wavelength shorted stubs.

You learned then that a one-quarter wavelength stub connected across the transmission line had no effect on the energy in the line and acted like an insulator between the two conductors. You also learned that a one-half wavelength shorted stub across the transmission line acted like a short between the two conductors.


NO EFFECT ON RF ENERGY
ACTS LIKE A SHORT ACROSS THE TRANS-MISSION LINES NO RF ENERGY CAN PASS
λ/4
λ/2
INPUT IMPEDANCE ALONG A *SHORT-CIRCUITED* LINE
R X X_L X_L X_L R X_C X_C X_C R X X_L X_L X_L R X_C X_C X_C R X X_L X_L X_L R
TO LOAD
FROM GENERATOR
SHORTED
λ/4
λ/2
3λ/4
λ
5λ/4

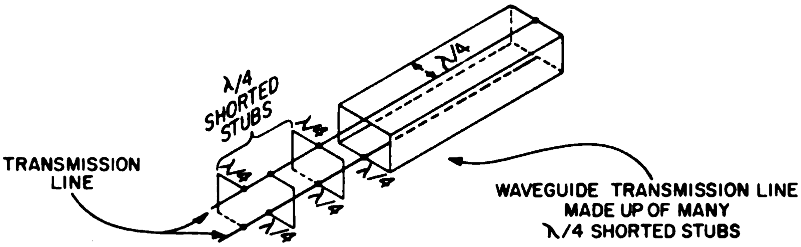
339.—Impedance across shorted transmission lines.

You can see from the diagram above that a short across the branch line is reflected as a low impedance at each half wavelength from the short. Also, note that at odd quarter wavelengths from the short that there are points of high impedance on the branch line. With the short being five-quarter wavelengths from the junction, the branch line will offer high impedance to energy down the branch line, but will not affect energy down the main line. With the short at one wavelength (or at one-half wavelength) from the junction, the short circuit on the branch line appears as a short circuit on the main transmission line. If the short circuit were a three-quarter wavelength (or one-quarter wavelength) from the main line, then the branch line would appear as a high impedance and would not affect the main transmission line.

THE DUPLEXER

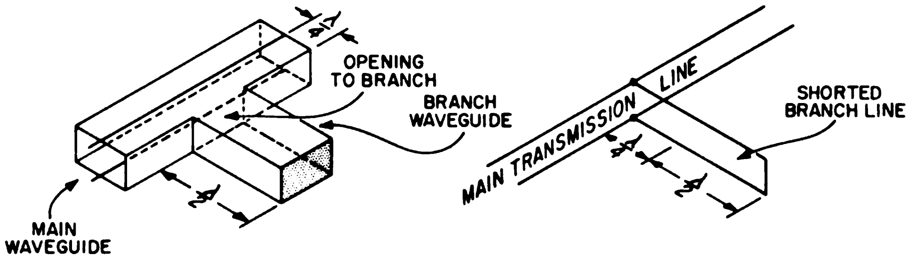
Waveguides

The one-quarter wave shorted stub is a metallic insulator. A metallic insulator may be placed at any point along a two-wire transmission line without affecting the energy along the line. By using one-quarter wave shorted stubs at all points along a two-wire transmission line, you will have a section of waveguide.


λ/4 SHORTED STUBS
TRANSMISSION LINE
λ/4
WAVEGUIDE TRANSMISSION LINE MADE UP OF MANY λ/4 SHORTED STUBS

340. —Waveguide section.

Shorted sections of waveguide perform important functions in a duplexer. Since a waveguide is a high-frequency transmission line, shorted sections of waveguide have the same effect on the main waveguide as shorted sections of transmission line have on the main transmission line. In comparisons between waveguide and transmission lines, it is essential that the shorted one-quarter wave stubs that make up the waveguide be considered. This means that a branch waveguide that is shorted at a point that is one-half wavelength from the wall of the main waveguide will have the same effect on the energy down the main waveguide as a three-quarter wavelength shorted stub has on a two-wire transmission line. Referring to the illustration on the opposite page, a short at the three-quarter wavelength point presents a high impedance to the energy down the shorted stub and has no effect on the energy transmitted down the main line. Also, if the short had been at a one-half wave point, as would be the case with a shorted waveguide arm that extends an odd quarter wavelength from the wall of the main waveguide, this would be reflected as a short across the main line.



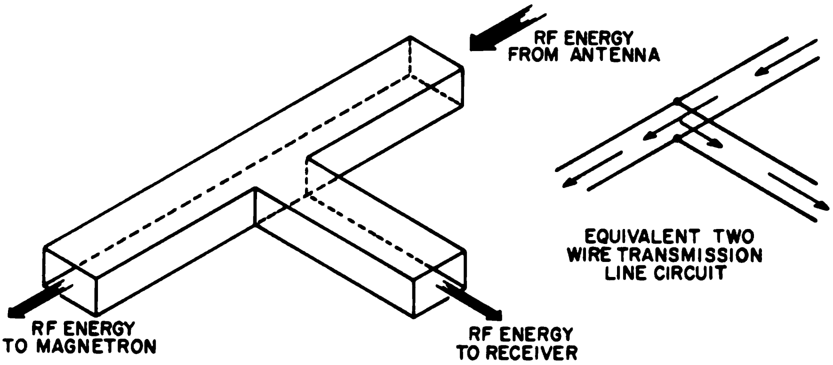
341. —Waveguide and transmission line equivalent circuits.

In the waveguide and transmission line equivalent circuits shown above, note that the branch arm of waveguide is connected to the narrow dimension of the waveguide. This is a parallel connection. It is this type of junction that will be used in duplexers.

If the branch arm were connected to the broad dimension of the waveguide, the connection would be a series junction. This type of junction will not be discussed in this topic.

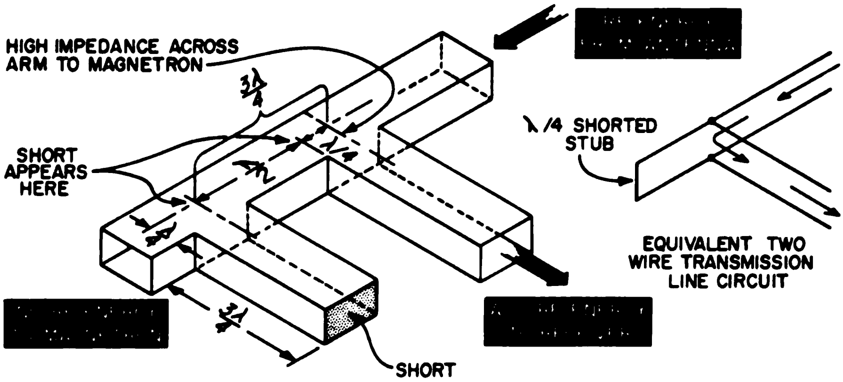
Receiving

Suppose that you had a parallel junction made of waveguide interconnecting the antenna, receiver, and magnetron as shown in the accompanying diagram. RF energy fed into the arm on the right from the antenna would divide equally at the junction. That part of the received RF energy going to the magnetron would be lost.



342. —Waveguide parallel junction.

Now see what happens when you connect a three-quarter wavelength shorted stub in the arm to the magnetron at an odd quarter wavelength point from the junction. The shorted stub presents a short across the arm to the magnetron. Since this short is at an odd quarter wavelength point from the junction connecting the antenna, receiver, and magnetron, the arm to the magnetron presents a high impedance to any energy down that arm. All of the RF energy from the antenna now goes down the arm to the receiver.


[redacted]
HIGH IMPEDANCE ACROSS ARM TO MAGNETRON
3λ/4
SHORT APPEARS HERE
λ/4
λ/4 SHORTED STUB
EQUIVALENT TWO WIRE TRANSMISSION LINE CIRCUIT
3λ/4
SHORT

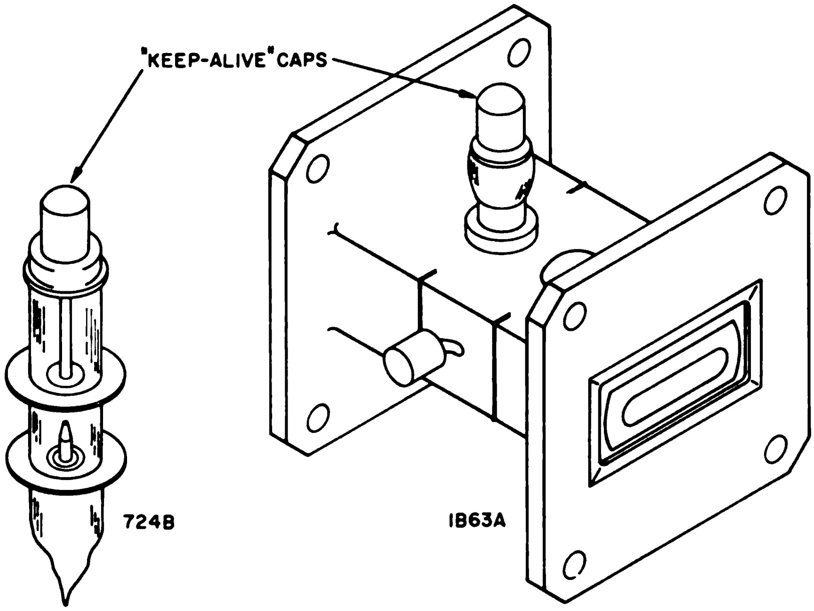
343. —Waveguide parallel junction with three-quarter wavelength shorted stub inserted.

Waveguide connections similar to those in the diagram above are used in a duplexer. The duplexer functions as a receive-transmit switch with receive as its normal position. It is the shorted section of waveguide that effectively closes the arm of the waveguide to the magnetron. This will permit all of the RF energy from the antenna to be connected to the receiver.

TR Tubes

Duplexers used in fire control radar equipments consist of sections of waveguide and TR tubes. It is the TR tubes that provide the fast switching action to switch from the normal receive position to the transmit position when the magnetron is oscillating.

A TR tube is a special gas tube with a spark-gap which is completely enclosed and sealed in a glass or metal envelope. A spark-gap is a gap between two electrodes across which a potential difference may exist. If this potential difference is high enough, the tube will fire, producing a short across the gap. The width of the gap determines the potential difference required to cause the tube to fire. In TR tubes used in radar equipment, the width of the gap is such that the transmitted RF energy will cause the tube to fire. At this time, the TR tube forms a short circuit across the waveguide. Normal returned RF signals will not cause the tube to fire since they are too weak, and at this time the TR tube appears as an open circuit across the waveguide.



344. —724B and 1B63A TR tubes.

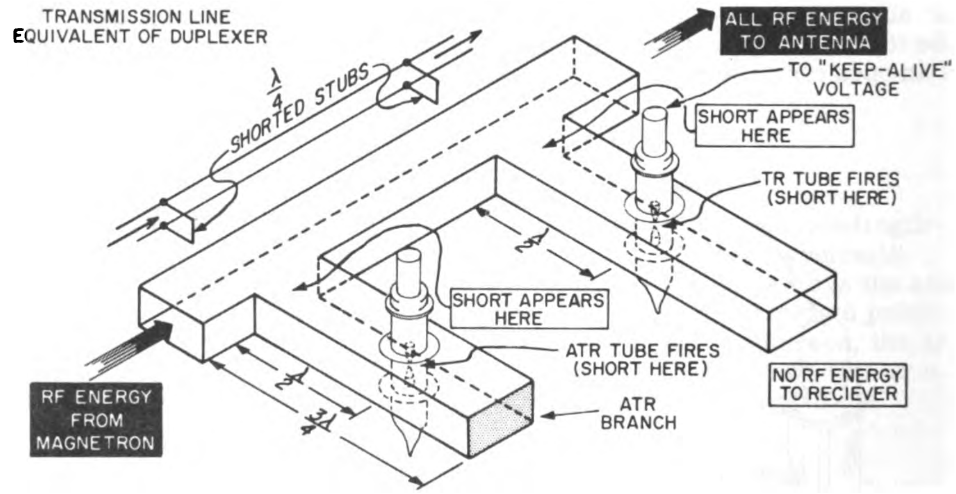
A negative voltage is usually applied to one of the electrodes of the TR tube and this voltage causes a small amount of current, microamps, to flow from the electrode to ground and maintains the gas partially ionized. When the transmitted RF energy from the magnetron reaches the electrodes, the TR tube will fire more radily. This negative voltage is referred to as "keep-alive" voltage; it aids the TR tube in performing its high speed switching action.

If the TR tube is inserted at the proper wavelength point in the waveguide, correct switching action will be obtained.

THE DUPLEXER

Transmitting

When the magnetron oscillates, it produces high-power RF energy. It oscillates for a very short duration of time. If this high-power RF energy were applied to a duplexer using only selected length sections of waveguide as shown with the duplexer (receive-transmit) switch in the receive position, a short would be present across the branch from the magnetron at the junction to the three-quarter wavelength shorted stub. To eliminate this short, a TR tube is placed one-quarter wavelength from the shorted end of the stub. When RF energy of high power enters this branch, the tube will fire and a short will be produced across the electrodes of the TR tube. This short appears as a short one-half wavelength away. It effectively closes this branch to all RF energy except that necessary to sustain firing of the tube.



345.—A basic duplexer during transmitted pulse.

The RF energy travels along the waveguide to the junction of the receiver. This high-power RF energy cannot be permitted to travel down this branch to the receiver as it would damage the receiver crystals. In order to protect the receiver while transmitting, another TR tube is located in the waveguide branch to the receiver. This TR tube is also located one-half wavelength down this branch. When transmitted RF travels down this branch, the tube will fire and produce a short across the electrodes of the TR tube. This short appears as a short one-half wavelength away; it effectively closes this branch to all RF energy except that necessary to sustain the firing of the TR tube.

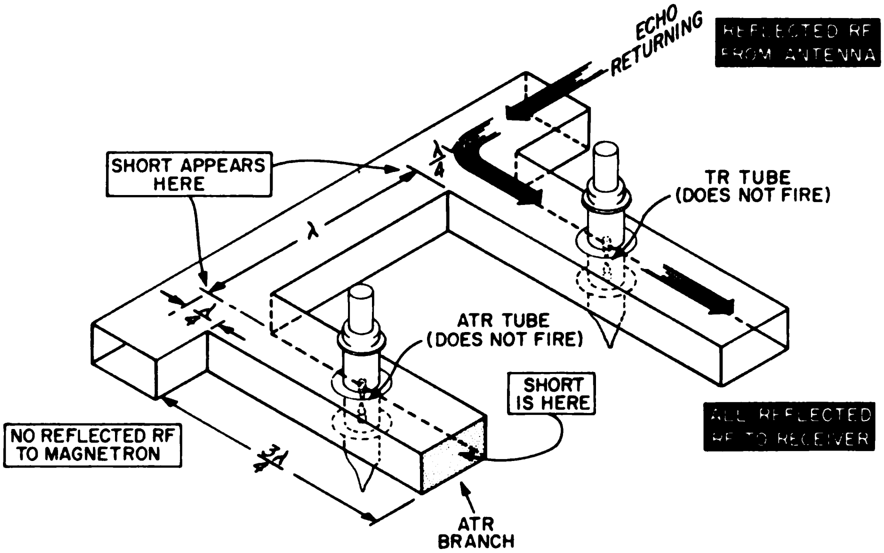
To afford greater protection to the receiver during transmission, "keep-alive" voltage is applied to an electrode in the TR tube. This permits the RF to cause the tube to fire more quickly and prevents excessive RF from damaging the receiver crystals. Some RF does get through to the receiver; it is this RF that produces the transmitter pulse that is seen on the radar indicators.

"Keep-alive" voltage is not necessary on the electrode of the tube in the shorted stub section of waveguide. This tube, identical to the TR tube in the receiver branch except for "keep-alive" voltage, is called an ATR tube. The shorted stub section is called the ATR branch.

Receiving

When the magnetron stops oscillating, there will be no high-power RF to maintain the shorts across the electrodes of the ATR and TR tubes. The duplexer (receive-transmit switch) has returned to its normal receive position. The short has been removed from across the branch to the receiver and a short now appears on the branch to the magnetron one-quarter wavelength from its junction with the receiver branch.

Reflected RF energy that enters the waveguide is not of sufficient power to produce shorts at the ATR or TR tubes. These tubes do not fire during reception of reflected signals. It is the ATR branch that effectively closes the branch to the magnetron when receiving.



346. —A basic duplexer during receiving period.

Review

1. A duplexer makes possible the use of one antenna for both receiving and transmitting.

2. A duplexer functions as a receive-transmit switch with receive as the normal position.

3. Critical lengths of waveguide and ATR and TR tubes make up a duplexer and enable it to perform its high-speed switching from receive to transmit and back to receive.

4. Waveguides are special high-frequency RF transmission lines.

5. When TR and ATR tubes fire, there is a short across the waveguide at the point where the tubes are located.

6. "Keep-alive" voltage, a high negative voltage, is connected to an electrode in a TR tube to maintain the gas at partial ionization. This produces a short more quickly when transmitting so as to provide additional protection to the receiver crystals.

TOPIC 19: FIRE CONTROL RADAR SPECIAL CIRCUITS

Review

You have completed your study of "Fire Control Radar Special Circuits." In it you have encountered many of the special circuits that are used in the radar equipments that are a part of the Gun Fire Control System that you will study next. In the circuit applications that were given at the end of each topic were circuits from Radar Equipments Mark 25, Mark 34, Mark 35, and Radar Sets AN/SPG-34, AN/SPG-48, and AN/SPG-50. You next will study one of these radar equipments and the GFCS (Gun Fire Control System) with which it is used.

All of the special circuits found in radar equipments have not been presented in this manual. Only those special circuits found in two or more radar equipments have been discussed. Circuits peculiar to one radar equipment will be taught with the specific equipment involved. Details of operation of these circuits will be found in the Ordnance Pamphlets for that radar equipment.

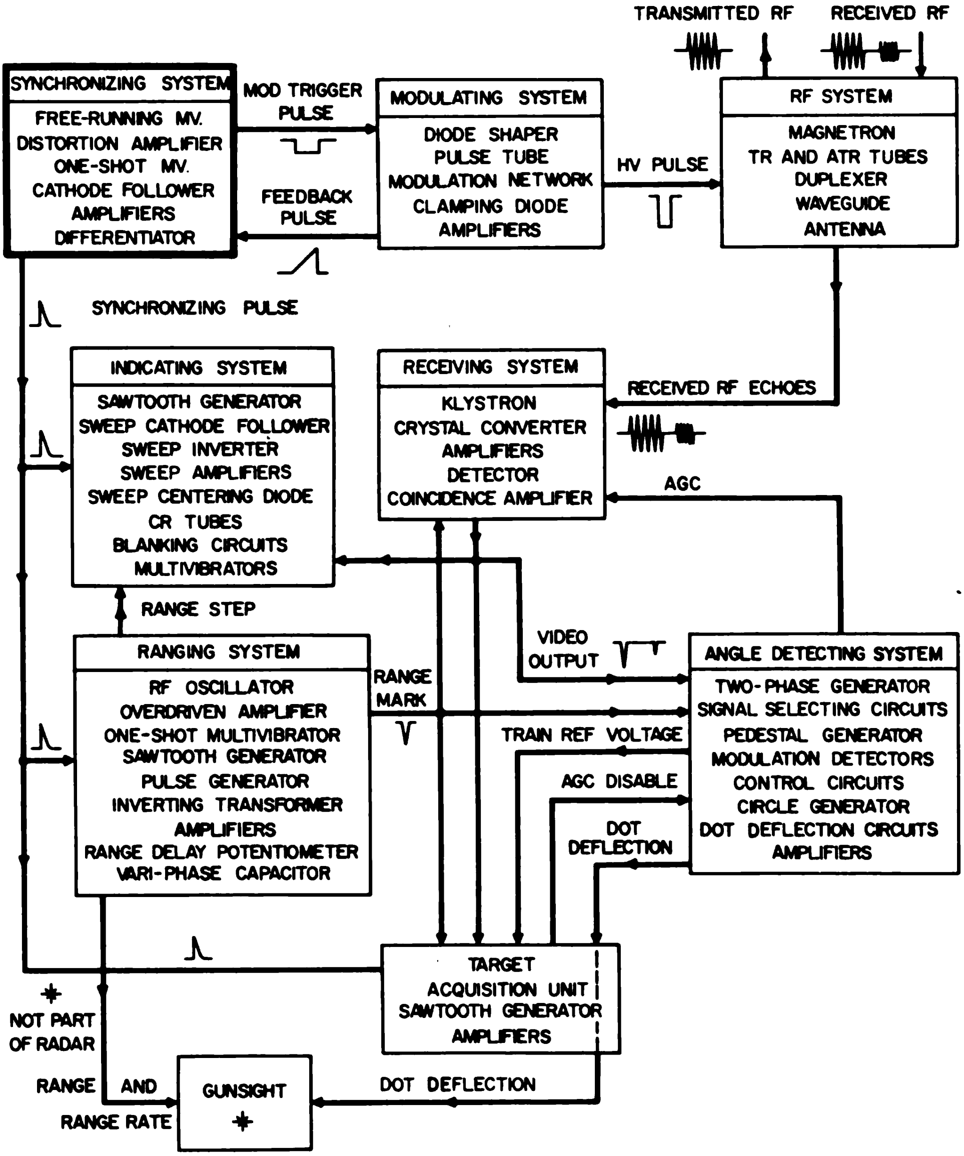
As you continue your training, in school and aboard ship, with specific radar equipments, you will find that an understanding of the operation of the special circuits will facilitate an understanding of the radar equipments. You will have many opportunities to demonstrate your understanding of these circuits. Your instructor, in the course on a radar equipment, will expect you to be familiar with these circuits. When you are assigned to a GFCS aboard ship, the performance of the radar equipment will be evidence of your understanding of fire control radar special circuits.

Since the operation of these special circuits is very important, you will want to review what you have studied about them. For a quick review of each type of circuit, refer to the review section at the end of each topic. You will continually want to reinforce your knowledge of special circuits. You may want to refer to "Fire Control Radar Special Circuits" when you encounter a special circuit in the radar in a system course or when you have a maintenance problem on a special circuit in an equipment aboard ship. A copy of this text will be made available as a reference in later courses and as a reference aboard ship.

Where will you encounter these special circuits?

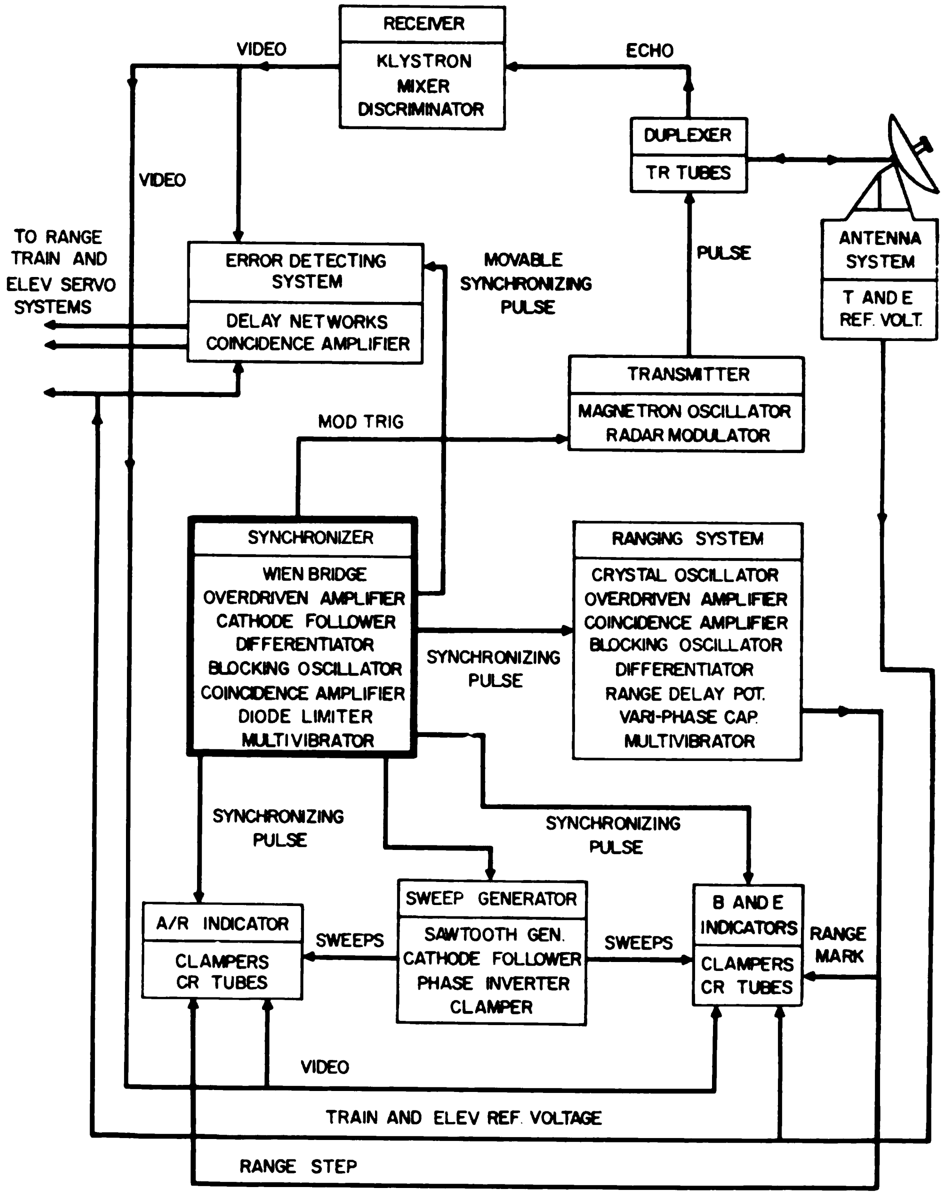
On the following pages are given block diagrams of three radar equipments. Operation of these radar equipments is divided into functional systems. Each of these functional systems is represented as a block in the equipment block diagram. In each block are listed some of the special circuits that are found in that block. The PRF of the radar will be generated in the Synchronizing System (Synchronizer). You will notice that two of these radar equipments use a free-running multivibrator to generate the PRF; the other one uses a Wien bridge oscillator. Two of these three PRF generating circuits you have already seen in the applications given at the end of each topic. Many of the circuits indicated in the blocks will not be new to you. They will have been studied in the applications or will be a variation of the basic circuits. You can see that you already are on your way toward an understanding of the operation of these radar equipments.

Review (Continued)



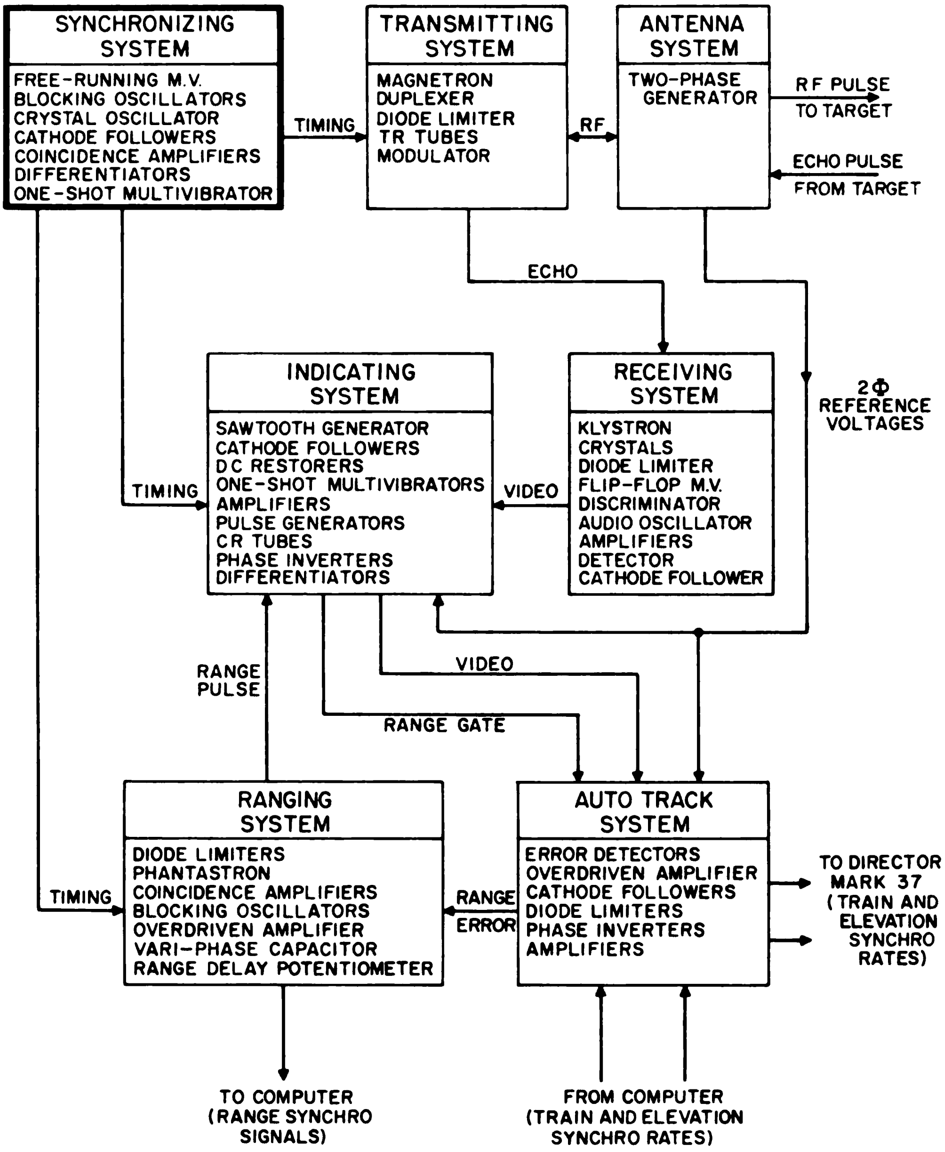
347.—Radar Equipment Mark 34 Mods 2, 6, and 16—system block diagram.

Review (Continued)



348. —Radar equipment—block diagram.

Review (Continued)



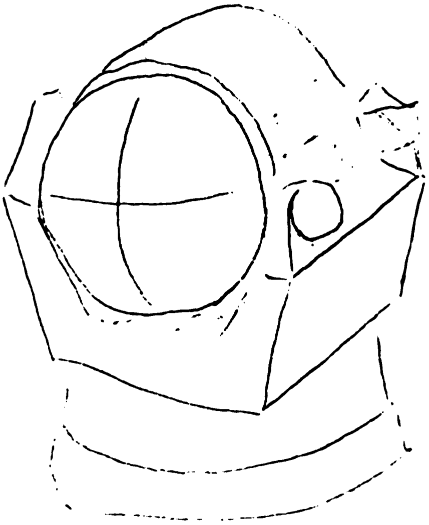
349.—Radar equipment—block diagram.

FIRE CONTROL RADAR SPECIAL CIRCUITS

Review (Continued)

You will use the knowledge gained from your study of fire control radar special circuits in your study of a specific radar equipment and in your work with that equipment aboard ship. When you are assigned to a Gun Fire Control System aboard ship, you will want to keep your radar operating at peak performance. To do this, and this is the job of a good FT, you must THINK. You will THINK about your equipment much of the time if you keep the out-of-operation time to a minimum. Before casualties occur, THINK of how to prevent them. Not all casualties can be prevented, so THINK—What would I do if this or that happened? Try to THINK of possible solutions to a trouble before the trouble occurs. Have a logical approach to casualty analysis. You have been using a logical approach to trouble shooting in the circuits in the special circuits chassis. The same approach will be used in trouble shooting aboard ship.

Your next assignment will be to learn the operation, adjustment, and maintenance of a Gun Fire Control System. From now on, you no longer will be working with a chassis designed as a training aid, but you will be working with the "real thing"—equipment designed for shipboard use. The individual circuits in the equipment—and there will be more of them—may have a different physical appearance than the same circuit in the chassis, but their operation will be the same. Your next assignment has been made easier by your training in "Fire Control Radar Special Circuits."



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* U.S. GOVERNMENT PRINTING OFFICE : 1962 O—[illegible]

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